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THE UNIVERSITY OF ALBERTA

THE EFFECT OF TIBIAL ROTATION ON ISOKINETIC KNEE FLEXION:
AN EMG STUDY

by

DANIEL BOLAND

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICAL THERAPY

EDMONTON, ALBERTA

SPRING 1986

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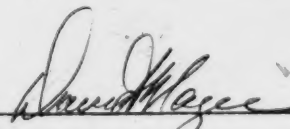
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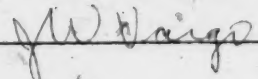
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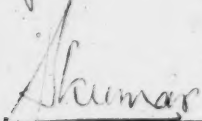
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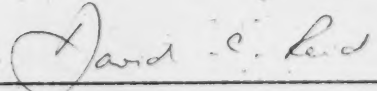
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Supervisor







DATE *December 13, 1985*

TO NANCY AND CHRISTOPHER

ABSTRACT

The purpose of the study was to determine the surface integrated electromyography (IEMG) produced by the lateral and medial hamstring muscles and the gastrocnemius during isokinetically-resisted knee flexion, with the tibia positioned in (a) normal rotation, (b) external rotation, and (c) internal rotation. In addition, torque values were measured. Nineteen normal females, aged 21 to 35 and not engaged in competitive athletics participated in the study.

All testing was performed with the participants in a stabilized sitting posture. Special seating modifications ensured the avoidance of external pressure from the seat on the surface electrodes and encouraged maximal efforts throughout the range of motion for the test movements.

A total of 12 maximal voluntary efforts (3 isometric; 9 isokinetic) were recorded for each subject. The isometric efforts represented the reference activity to which the subsequent IEMG and torque data were compared.

A two-way analyses of variance with repeated measures on both factors was performed for the recorded activity of the lateral hamstring muscles, medial hamstring muscles, the gastrocnemius muscle, and for knee flexor torque. Three tibial positions and four knee angles (10°, 30°, 60°, 90°) were analyzed. Post-hoc comparisons were performed on significant main effects, using the Tukey procedure.

The established IEMG-muscle length relationship for striated muscle did hold true for the gastrocnemius muscle but not for either lateral or medial hamstring groups. The indeterminate variable of mechanical leverage was a probable factor in influencing these results.

The torque analyzed with respect to angle followed the pattern reported by previous authors regarding isokinetic knee flexion. The maximum torque for the knee flexors, occurred earlier in range than was predicted by three biomechanical models presented. The discrepancy was attributed to the effect of the length-tension relationship of striated muscles, and muscle force lever alterations through range of angular displacement.

The IEMG data did not support the practice of selectively rotating the tibia, in combination with isokinetic knee flexion, to emphasize the medial hamstrings (semitendinosus and semimembranosus) or the lateral hamstrings (biceps femoris). Thus, the proposal of such exercises for rehabilitation of rotatory instabilities of the knee is not substantiated by the present study. An unexpected finding was the reduction in torque production during isokinetic testing in internal tibial rotation, with respect to the other tibial positions. Concomitant reduction in overall IEMG production was also observed.

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LIST OF ABBREVIATIONS

cm	centimetre
°	degrees
°/s	degrees per second
ER	external rotation
ft	foot
ft lb	foot pounds
Hz	Hertz
IEMG	integrated electromyogram
IR	internal rotation
mm·s ⁻¹	millimetres per second
ms	milliseconds
min	minutes
MVC	maximum voluntary contraction
NR	normal rotation
%	percent
lb	pounds
RM	repetition maximum
RPM	revolutions per minute
s	seconds

CHAPTER ONE

INTRODUCTION

Background to the Problem

Progressive strengthening of periarticular musculature is a large component of rehabilitation for many patients treated by physiotherapists. A thorough knowledge of the physiological and biomechanical functions of the musculature would greatly enhance the prospect of implementing effective exercise programmes. Although there has been a great proliferation of experimental data on the functions of the quadriceps muscles, relatively little attention has been focused on the hamstring group of muscles.

Standard texts¹⁻⁷ have acknowledged the role of the medial and lateral hamstring muscle groups as selective rotators of the knee joint, in addition to their collective function as flexors of the knee.

Electromyographical studies have been used to determine the functions of the hamstrings as rotators of the knee joint.^{17,66,77} However, this information is limited in quantity. Furlani et al.¹⁷ employed coaxial needle electrodes to record the electrical activity of the long

and short heads of the biceps femoris muscle. It was concluded that this muscle was not always active in the movements of the lateral rotation of the leg, lateral rotation of the leg with the knee in flexion, or lateral rotation of the thigh on a fixed foot. Lyons et al.¹⁸ suggested that the functional difference between the semimembranosus and the biceps femoris muscles during the stance phase of gait was that the biceps femoris was necessary to restrain excessive internal rotation of the tibia. Electromyography had shown the biceps femoris to have an increased electrical activity compared to a diminished semimembranosus activity during this phase of gait.¹⁸

In recent years, the topic of tibial rotation has received increasing attention, especially in its relationship to rotary stability of the knee joint.⁷⁻¹³ There has been disagreement among authors regarding the angle of knee flexion at which the greatest tibial rotation was available. The knee angle of 90° has been suggested by some authors.^{1,13,14} Recent research^{9,11} indicated that the potential for tibial rotation increased with the degree of knee flexion (i.e. including angles beyond 90°).

It has been suggested¹² that pre- and postsurgical rehabilitation of the knee has seldom reflected the

rotational component of knee motion; rather, this articulation has been treated in therapeutic terms, as a pure hinge joint. Robertson¹² indicated that the medial rotators of the knee were strengthened more successfully by performance of isotonic exercise into medial rotation, than by performing isotonic knee flexion exercises. The author proposed that, in light of his findings, knee rehabilitation regimes might benefit by the inclusion of resistance training specifically into tibial rotation in order to optimize strength gains of the knee rotator muscles.¹²

Recent publications^{19,20} described isokinetic exercise routines for knee flexor muscles, including knee flexion combined with active tibial rotation throughout the resisted range of motion. This combination of exercise was intended to isolate the lateral hamstring muscles when external tibial rotation was employed, and to isolate the medial hamstring muscles when internal tibial rotation was employed.

In order to substantiate the effectiveness of the above-described combinations of resisted isokinetic knee flexion-tibial rotation, further study was required to determine, among other concerns, the kinesiological function of the medial and lateral hamstring muscles during the exercise movements in question.

Statement of the Problem

The role of the medial and lateral hamstring muscle groups as selective rotators of the tibia at the knee joint is generally accepted. There is little documentation from the research literature regarding the respective contributions of the medial and lateral hamstring groups to active knee joint rotation. It has also been suggested^{19,20} that active tibial rotation combined with isokinetic knee flexion is an effective method of biasing or isolating the medial and lateral hamstring groups during internal and external tibial rotation, respectively, for purposes of rehabilitation of rotational instabilities of the knee.

Physiotherapists have the option of including or excluding tibial rotation with resisted knee flexion when instructing patients in strengthening the hamstring muscles. This decision would be more judiciously made with the knowledge of the activity of the hamstring muscles during the described exercise combinations. The necessary information was not available, thus requiring further research into the area.

The role of the gastrocnemius muscle as an assistive knee flexor has been acknowledged^{1,2,60,67,82-84} but has

not been a focus of quantitative electromyographic investigation and therefore required more study in order to elucidate the contribution of this biarticular muscle to knee flexion.

Objectives of the Study

1. To determine the electrical activity produced by the medial and lateral hamstring groups, and by the gastrocnemius muscle, during slow isokinetically-resisted knee flexion when combined with each of three defined positions of tibial rotation.
2. To determine the torque produced during the same defined test conditions.

Research Hypotheses

1. The mean % IEMG will differ significantly among the four angles of knee flexion analyzed, for the following muscles: (a) lateral hamstrings (biceps femoris long head and short head), (b) medial hamstrings (semitendinosus and semimembranosus), and (c) gastrocnemius.
2. The mean % torque will differ significantly among the four angles of knee flexion analyzed.

3. The mean % IEMG will differ significantly among the three positions of tibial rotation analyzed for the following muscles: (a) lateral hamstrings, (b) medial hamstrings, and (c) gastrocnemius.
4. The mean % torque will differ significantly among the three positions of tibial rotation analyzed.

Significance of the Study

Traditional physiotherapy regimens for knee rehabilitation have neglected the fact that the medial and lateral hamstring muscle groups contribute to rotational stability and that these muscle groups can work independently from each other while performing their rotational functions.

Recent literature in orthopaedics has refined the concepts of rotational instability and, in doing so, has highlighted the importance of the rotators of the knee, the semimembranosus, pes anserinus (semitendinosus, gracilis, sartorius), and biceps femoris in particular. From this newer knowledge has come the concept of training the hamstrings specifically in their role as rotators of the tibia at the knee joint.^{11,12,19,20}

> One such rehabilitative concept was that of performing isokinetically-resisted knee flexion with

either medial or lateral rotation, for the purpose of rehabilitation of patients with rotational instabilities of the knee.^{19,20}

A review of the literature demonstrated that little has actually been done to define the activity of the hamstring muscles during voluntary active tibial rotation, either in isolation or in combination with resisted knee flexion exercise.

A method which is frequently employed to determine the kinesiological characteristics of muscles, is that of surface electromyography. Integrated electromyography (IEMG) has often been used in order to assess muscle activity in quantitative terms. The present investigation endeavored to define the relative activity of the lateral hamstring, medial hamstring and gastrocnemius muscles during various defined movement combinations involving isokinetically-resisted knee flexion and tibial rotation. This information will be valuable in establishing the rationale of rehabilitation exercise combinations.

Operational Definitions

1. Surface integrated electromyography (surface IEMG).
The placement of surface electrode pairs to detect the

electrical activity of muscle is the preferred method when kinesiological studies of surface muscles, involving a global pick up of muscle activity is desired.³ The raw EMG signal is stochastic in nature. For this reason it must be processed to obtain suitable quantitative values for analysis. The most frequently employed method includes rectification of the EMG signal, followed by smoothing of the signal.³⁰ For the present study, the term integrator was used to indicate the application of a first order low pass filter, having the time constant selected at 250 ms, to the output of a full wave rectifier.⁹⁴

Bouisset and Maton⁵⁸ found that a linear relationship existed between surface IEMG and intramuscular (needle electrode) IEMG, during nonisometric submaximal voluntary movements.

2. Medial hamstring muscles. This term refers to both the semitendinosus and semimembranosus muscles. The surface electrodes receive a global pick up from the activity of muscle fibres below the electrodes. The surface electrodes were placed over the motor point of the semitendinosus muscle, but due to the proximity of the semimembranosus muscle it must also have contributed to the electrical activity from this site.

3. Lateral hamstring muscle. The biceps femoris long head and short head are included in this definition. The surface electrodes were placed over the motor point of biceps femoris long head, but it was assumed there was overflow from the juxtaposed short head. Thus, the term lateral hamstrings was used to include both heads of the biceps femoris muscle.

4. Torque. Torque is described as the product of a force that acts about an axis of rotation times its perpendicular distance from the axis.²¹ Torque is most often measured in foot-pounds or in Newton-meters. In the present experiment torque was measured and registered by the Cybex II dynamometer. The torque included the torque produced by active knee flexion, by the weight of the radial arm and ankle pad of the dynamometer, and the weight of the subject's limb.

5. Isometric contraction. The activation of a muscle causes the contractile components, the myofibrils, to shorten, resulting in stretching of the connective tissue and tendon of the muscle. When no joint movement occurs, during such a muscle contraction, the contraction is termed isometric.²² The resistance may be immovable or too great for the muscle involved to overcome. In this situation, the resistance is in direct ratio to the force applied.²³

6. Isokinetic contraction. In an isokinetic contraction, maximum effort is exerted during the performance of a concentric muscle contraction. The angular velocity of the limb segment is held constant throughout the range of motion employed. The Cybex II dynamometer system registers strength as torque.²⁴

7. Test positions.

(1) Normal. Several studies⁸⁻¹¹ which have investigated tibial rotation of the knee joint have encountered the problem of defining "neutral". The placement of the foot perpendicular to the frontal plane of the body is often misleading with regard to the true neutral position for the individual. This confusion is due to the variation among persons regarding tibial torsion present normally (i.e. in a free-hanging resting posture).¹¹ Therefore, for the purposes of the present study the term "normal rotation" (NR) was adopted to indicate that tibial position which the tibia naturally assumed when the subject relaxed her lower limb prior to each test repetition. The position was assumed to be the normal midposition between maximum external and internal rotation for that subject (Plate 1).

(2) External rotation. When the subject actively rotated her tibia around its longitudinal axis so that the aspect of the tibia which initially faced anteriorly now

faced more laterally, this position was termed the externally rotated position (ER). The subject maintained a maximal voluntary external rotation throughout the entire test repetition (Plate 2).

(3) Internal rotation. When the subject actively rotated her tibia around its longitudinal axis so that the aspect of the tibia which initially faced anteriorly now faced more medially, this position was termed the internally rotated position (IR). The subject maintained a maximum voluntary internal rotation throughout the entire test repetition (Plate 3).

All test positions included active dorsiflexion of the ankle to discourage movement of the ankle and foot, thus promoting a concentration of tibial rotation at the knee joint during each test repetition. The maintenance of active dorsiflexion was also intended to diminish unwanted alterations in gastrocnemius length that would ensue from uncontrolled ankle positioning.

Delimitations

1. The investigation was restricted to 20 females in the age range of 21 to 35 years. The normal activity level of the subjects in recreation or athletics was not a consideration for admission to the study. None



Plate 1. Test Position: Normal Rotation



Plate 2. Test Position: Internal Rotation



Plate 3. Test Position: External Rotation

of the subjects had a previous history of trauma to the test limb or to the lower spine of sufficient severity to have required medical attention or to have interfered with the performance of the tasks required of the subject during the study.

2. The study was limited to a kinesiological investigation using IEMG to delineate the electrical activity of the lateral hamstrings, the medial hamstrings and the gastrocnemius muscle during isokinetically-resisted knee flexion. The knee flexion was combined with one of three test positions - normal rotation, external rotation or internal rotation - around the long axis of the tibia, relative to the stabilized femur. The study was performed with the subject in a sitting position. The EMG was detected using stainless-steel surface electrodes for purposes of global electrical pick up from each of the three muscle groups.
3. An attempt to control the movement of the ankle joint was made by instructing the subjects to maintain their ankles in active dorsiflexion. Thus the tendency for subjects to alter the angle of the ankle and hence the length of the gastrocnemius muscle was expected to be negligible. A change of muscle length would have the

effect of decreasing the reliability of the gastrocnemius IEMG values recorded, with regard to the IEMG-tension relationship.

4. Other major known variables included the range of knee flexion which was restricted for purposes of data collection to between 10° and 90° . The hip angle of each subject was approximately 105° which matched the inclination angle of the Cybex II back rest. The supine position represented a reference hip angle of 180° . The trunk, thigh, and leg were stabilized with belts and velcro fasteners as included with the Cybex II system (Plate 4).
5. The data collected included IEMG recordings using surface electrodes at 30° of knee flexion for the isometric reference activity and at 10° , 30° , 60° , and 90° for the isokinetic repetitions. Torque values were also recorded during all test performances.
6. Ideally, all subjects would have been equally familiar with the Cybex II system and with the test movements required. An effort was made to diminish the familiarity gap by having each subject undergo a practice session at least 48 hours prior to the test day, and not exceeding one week before testing. The session involved repeated submaximal and maximal



Plate 4. Stabilization of subject with belts and velcro fasteners

contractions in the test positions. In this manner the learning effects associated with strength gains were expected to have been largely reduced, allowing more reliable and valid data to be collected.

Limitations

1. The selection of subjects was made on a volunteer basis and did not, therefore, constitute a random sample. The order of test conditions, however, was randomly selected.
2. Each subject's interpretation of a maximum voluntary effort was potentially different during the course of the study. Such interpretation would have depended, in part, on each subject's past experiences in performing maximal muscular contractions. Those subjects with an athletic background might have been expected to perform closer to their physiological maximum. However, the ability of each subject to perform consistently with respect to their maximum potential was a more important consideration because relative torque values from repetition to repetition were of interest, rather than absolute torque values. Therefore, the ability of subjects to perform consistently may have been related to their level of experience in maximal effort contractions.

3. The research design called for one practice session prior to test day procedures. The effectiveness of familiarizing each subject with test day conditions was an unknown factor. Time restrictions and subject compliance were the main considerations in limiting the study to one practice session and one test session.
4. The intensity and physiological effects of the warm up session prior to data collection on the test day were unknown variables for each subject. The subjects were asked to perform submaximal efforts and maximal voluntary contractions isometrically and isokinetically. The submaximal efforts were to achieve approximately 50% of maximal levels. The warm up efforts were not recorded and therefore no indications of actual effort levels were available. Variation no doubt existed among subjects in their ability to estimate the requested effort levels. Thus, the level of preparation by each subject prior to actual data collection would subsequently be different. In that warming of muscle is known to modify an individual's work capacity,²² the results of the present study may have been influenced by the variability in warm up levels anticipated.

5. Goniometric measurement was required in order to match the IEMG and torque values to specific angles of knee flexion. One aspect of this procedure involved aligning the shaft of the femur with the horizontal. The line of the femoral shaft was estimated through visual inspection and palpation of the region. A more exact method would have involved radiography, but such procedures were not available to the experiment. Therefore the less precise nature of the method employed for the present investigation must be considered as a limitation of the experiment.
6. Stabilization of the thigh was obtained by the use of the thigh strap anchored to the Cybex II table. Resisted knee flexion caused the subject's thigh to push firmly upward so as to brace against the taut strap. During test movements involving tibial rotation, some test adduction or abduction of the thigh was sometimes noted. Hence, it was expected that biomechanical variations might occur involving the muscles tested; however these variations, if present, were indeterminate. Construction of rigid stabilization for the thigh would have decreased the generalizability of the present data to the clinical situation. Therefore, standard stabilization

procedures as advocated by the Cybex II manufacturer*
were adhered to.

*Cybex II. Lumex isokinetic system (serial number C3080)
Lumex Inc., 100 Spence Street, Bay Shore, New York 11706.

CHAPTER TWO

REVIEW OF THE LITERATURE

The Basis of Electromyography

The cellular unit of contraction in skeletal muscle is the muscle cell. During contraction, it will shorten to about 57% of its resting length. A widespread, rapid series of twitches occur asynchronously among fibres, giving the appearance of simultaneous contraction of all muscle fibres. Hence, the seemingly smooth contraction is in reality a summation of asynchronous twitches.²⁵

The maintenance of a potential difference across the cell membrane of the muscle fibre is of basic physiological importance to its function.²⁶ In both nerve and muscle cells, there is a different chemical composition on each side of the semipermeable cell membrane. The internal medium contains a lower concentration of sodium (Na^+) and a higher concentration of potassium (K^+). In order to maintain the difference in ion concentration across the resting cell membrane, there must be a forced movement of Na^+ outward and K^+ inward.

Aerobic metabolic processes supply the energy to activate the sodium and potassium pumps to effect the maintenance of the desired equilibrium. When the axon is stimulated, and if the resting membrane potential (RMP) dips below a critical value (about -60 mV), there is a free passage through the membrane of Na^+ ions into the cell, i.e., down their concentration gradient, causing a depolarization of the membrane. The RMP is about -70 mV, whereas the "equilibrium potential" for Na^+ will be approximately $+60$ mV. Thus, one would expect the potential change (i.e. action potential) to be $70 + 60 = 130$ mV. However, the actual height of the "action potential" is only about 100 mV, due to the fact that there is a simultaneous outflow of K^+ ions down their electrochemical gradient. The movement of ions back to their original distribution is then effected by the Na^+ and K^+ pumps. In fact, there is a resultant "after-hyperpolarization" adding 5 mV to the RMP (Figure 1).²²

The action potential in the muscle fibre is propagated in both directions from the site of initial depolarization along the muscle fibre.²⁸ The depolarization, generates an electromagnetic field in the vicinity of the muscle fibre. Hence, with the electrode strategically placed, electrical changes caused by depolarization and repolarization give rise to the main

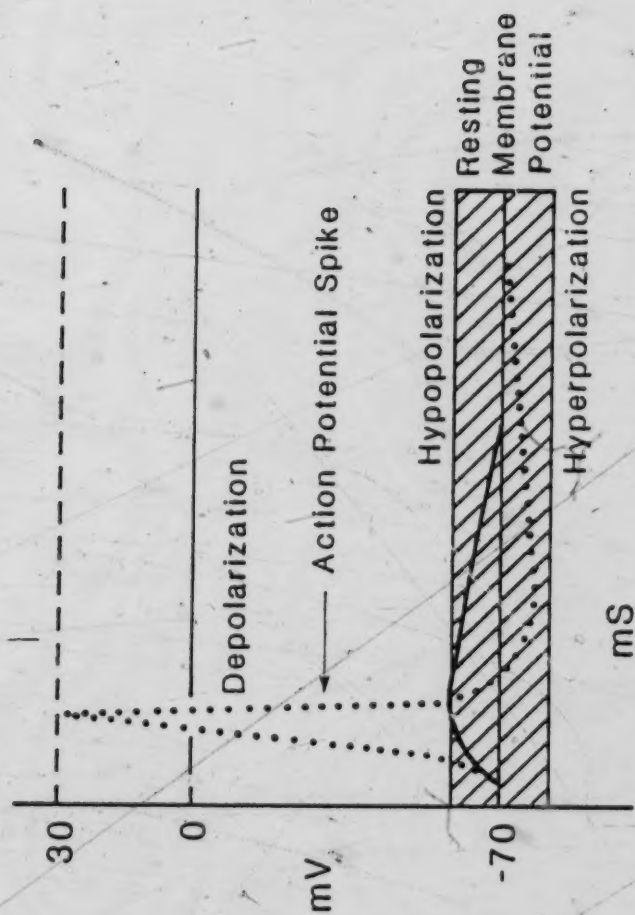


Figure 1. The depolarization of a nerve (modified from Åstrand, 1977)

deflections of the action potential seen in electromyography. It should be noted also that the depolarization, once commenced, always proceeds to completion. It either appears fully developed or it does not occur.²⁶

The Motor Unit

The nerve cell body, or alpha motoneuron, its axon, and its terminal branches, with all the muscle fibres supplied by the branches, together constitute a motor unit.^{25,30} A depolarization wave descending the nerve axon causes all of the muscle fibres in that motor unit to contract almost simultaneously.²⁵ The muscle fibres of the same motor unit interdigitate with those from other motor units. Thus, these contractile units are distinguished by innervation, not by position within the muscle.²⁹

A motor unit will have from five to about 2000 muscle fibres, and rarely has a polyneuronal innervation.²² The extrinsic eye muscles have from three to six muscle fibres per motor unit, whereas the gastrocnemius has approximately 1700 muscle fibres per motor unit. Thus, generally, those muscles controlling fine or delicate movements have the smallest number of muscle fibres per motor unit. Large muscles, such as those of the thigh, have much larger motor units.²⁵

The functional significance of motor unit properties is as follows: motor output is graded by recruitment of motoneurons. Because they have the lowest threshold, the smallest motoneurons will be recruited initially. When the force of contraction is increased, the larger motoneurons will be recruited, increasing the amount of tension developed. Although the terms "large" and "small" are utilized, there is actually a graduation of motoneuron sizes.²⁷ The amount of tension developed in the larger, faster motor units exceeds that generated by smaller, slower motor units, because fast motor units consist of a larger number of muscle fibres.³⁰ Another factor based on motor unit characteristics is that the smaller motor units require a lower discharge frequency to achieve tetanus than do the larger motor units.³⁰ This difference is due to the presence of a long post-spike hyperpolarization, which is explained by (a) the presence of a long positive after-potential, and (b) recurrent inhibition via Renshaw cell's activated by collaterals from phasic and tonic motoneurons.²⁷ The smaller, slower fibres will fuse their contractions into tetanus at frequencies of about 20 Hz, compared to approximately 50 Hz for the larger, faster fibres.²²

The Motor Unit Action Potential.

Depolarization of the sarcolemma of a muscle fibre,

results in propagation in both directions along the fibre, and an electromagnetic field is generated. A recording electrode located within this field will detect the waveform consisting of the spatiotemporal summation of individual muscle fibre action potentials from muscle fibres in the vicinity of the electrode. The detected waveform is known as the motor unit action potential.³

The amplitude of the action potentials is dependent on the diameter of the muscle fibre, the distance between the active muscle fibre, and the recording site, as well as the filtering properties of the electrode. The filtering properties of a bipolar electrode are a function of the size of the recording contacts, the distance between the contacts, plus the chemical properties of the metal-electrolyte interface.³

Because the depolarizations of the muscle fibres of one motor unit overlap in time, the signal at the recording site will constitute a spatial temporal superposition of the contributions of the individual action potentials. The signal is called the motor unit action potential (MUAP). If muscle fibres from other motor units are present in the detection range of the recording electrode, and they are excited, their MUAPs will be detected as well.³

The Relationship Between EMG and Tension

Early studies by Lippold³² and Bigland and Lippold³³ spurred interest in understanding the relationship between the electrical activity of striated muscle and the concomitant tension produced during contraction of these muscles. Lippold³² found a linear relationship to exist between IEMG and external force recorded in isometric conditions, whether submaximal or maximal voluntary efforts were produced, in the gastrocnemius muscle. Many researchers³⁴⁻³⁹ have investigated the EMG-force relationship in many muscles since that time. Several authors^{35,38,39} reported a linear relationship during isometric MVC, whereas others^{36,37} established a curvilinear relationship.

Bigland and Lippold³³ found that when the force of contraction varied with the rate of muscle shortening, i.e. concentric contraction, kept constant, a linear relationship was present between the IEMG and the load. This relationship persisted throughout the range of constant velocities tested, although the slope of the line varied between individuals and within each subject from one test to the succeeding test.³² Komi⁴⁰ and Eloranta and Komi⁴¹ tested the relationship between IEMG and muscle tension for the elbow flexors,⁴⁰ and for the vastus

medialis, vastus lateralis, rectus femoris, and semimembranosus muscles during active isotonic knee extension.⁴¹ Linearity was established between IEMG and tension at constant velocities of muscle shortening for the elbow flexors when submaximal voluntary efforts were elicited.⁴⁰ Submaximal and maximal efforts were shown to produce a similar relationship between IEMG and tension for the knee extensors, acting concentrically, and for the antagonistic semimembranosus muscle, again at constant velocities of contraction.⁴¹

To summarize, it can be stated that for submaximal and maximal voluntary efforts, for isometric and concentric (constant velocity) efforts, relationships between IEMG and muscle tension have been established for various muscles by several investigators. The precise nature of this relationship is controversial and appears to vary in part, with the characteristics of the actual muscle being tested and were established in the context of controlled laboratory settings, with strict control of variables and precise specification of experimental procedures.

The EMG and Fatigue

A variable which has not always received due consideration in electromyographic studies, is that of fatigue. DeVries⁴⁹ established that, if the fatigue factor was not adequately controlled, the result would be an upward shift in the IEMG-force curve as time progressed during an experiment, due to the fact that fatigue causes rapid increases in the production of IEMG per unit of force. According to Wittekopf,¹²⁵ the options available for a muscle to increase its force of concentration are by (a) recruiting more fibres or (b) creating synchronized volleys of motor unit activation. The same options are available when a constant force is held over a period of time, i.e. during the fatiguing process. The series of events leading to these phenomena have been hypothesized as follows: as the functional efficiency of particular motor units diminishes, the afferent muscle spindles are excited.¹²⁵ Thus, perhaps due to the stretch reflex,⁴⁷ a strengthening of the gamma efferent system is triggered, leading to the engagement or recruitment of fresh motor units as well as synchronization of their activity. These two factors counter the decreased functional efficacy of the whole muscle and lead to superposition of the electrical activity potentials of the motor units, leading

to a consequent increase in the amplitude of the global EMG recording.¹²⁵ Corroborative opinions on the roles of recruitment^{31,40,45} and synchronization^{40,45} are found in the literature. Studies were carried out to plot the amplitude of global EMG over time, when the subject maintained a constant isometric force in the monitored muscle or muscle group.^{36,41,45-47,51,52} These authors determined that there was a linear relationship between IEMG and time to fatigue. Petrofsky⁴⁶ found this linear relation to be accurate for the adductor pollicis, quadriceps femoris, and for handgrip. For the biceps brachii, however, the relationship was non-linear.

If the strength of contraction is increased during a fatiguing contraction, the plotted line between IEMG and time, is steeper.^{36,47,52} Further, Edwards and Lippold⁵⁰ demonstrated in the soleus muscle that the relationships between IEMG and tension remained a linear one, even after a four minute fatiguing contraction. The slope of the line was steeper following the fatiguing effort. Vredenbregt and Rau³⁶ graphed the EMG-force relation in the presence of fatigue, showing a nearly parallel rise in both parameters at various levels of constant force. This relationship was not described by the authors. Petrofsky et al.⁴⁶ also found the amplitude of EMG to be related to tension at the point of fatigue for the handgrip muscles, adductor pollicis, and quadriceps femoris.

Stephens and Taylor⁴⁸ carried out investigations of the effects of fatigue on IEMG and isometric maximal voluntary contractions. From their study, they defined two stages of fatigue. Within the first minute of MVC a loss of 50% of strength was seen, accompanied by a similar reduction in IEMG. The second stage saw tension diminish a further 25% (compared to MVC). However, the decrease in the EMG was not as great. The phase I decrease was attributed by the authors to fatigue at the site of the neuromuscular junction. The phase II decrease was attributed to contractile element fatigue, especially in the low-threshold units. A great controversy exists with respect to the actual site(s) of fatigue in various muscular efforts, and is beyond the scope of the present study. Scherrer and Bourguignon⁴⁵ stated that the total amount of electrical activity during a maximal isometric contraction may be substantially less than that generated following a period of hard work in the same muscle. These writers theorized that a deficiency in the electrical and mechanical phenomena, in addition to the advent of synchronization of motor units combined to create the electromyographic appearance observed during prolonged and intense muscular activity.⁴⁵

In summary, when conducting investigations in which the quantitative relationship between electromyography and

muscular tension is being examined, the probability of fatigue affecting the results must be avoided, as much as possible.⁴³

The EMG and Muscle Length

The effect of the relative length of a muscle on the electrical activity which can be elicited by voluntary contraction, has been a focus of controversy in the literature. Liberson et al⁵⁴ studied brief isometric maximal voluntary contractions in several muscles, at a number of joint angles, and isotonic full-range movements using a 10 repetition maximum (RM) resistance and a 1 RM resistance for the triceps muscle. The investigators found a decreased mechanical output and diminished IEMG magnitude at shortened lengths of contracting musculature. A marked parallelism was noted between IEMG and mechanical output. A greater IEMG with shortened muscular length was found only in the gastrocnemius muscle, and was attributed by the authors to technical problems associated with gross changes in the shape of the muscle during contractions and thus was considered to be an artifact-engendered anomaly.⁵⁴ Moritz et al⁵⁹ examined the knee extensor muscles performing voluntary isometric maximal voluntary contractions at five knee flexion angles

from 10°, i.e. near knee extension, to 90°. With maximum voluntary contraction of the quadriceps, the mean amplitude of the IEMG increased with a progressive increase in the knee flexion angle. In contrast to the torque curve, the curves of the IEMG displayed an increase throughout the tested range, i.e. as flexion, and thereby muscle length, increased. As stated by the authors, contraction force was affected, indirectly, through the effect of flexion angle on muscle length. For the quadriceps, the relation between relative muscle length and flexion angle was assumed to be proportional. The authors concluded that the torque was affected by both a change in lever arm and, of equal importance, by changes in relative muscle length.

Other investigators^{34,46,53,56,57,60,61} determined that the EMG was increased at relatively shortened lengths of voluntarily contracting muscle. This relationship was established in the performance of isometric maximal voluntary efforts,^{34,53,56,57,61} as well as for submaximal isometric efforts.^{46,53} The relationship was also confirmed under submaximal concentric contractions at constant velocities.^{53,60} It has been observed also that muscles which begin contraction at lengths beyond resting length, show lower EMG amplitude^{56,57,61} and action potential counts.⁶¹

Lunnen and his associates⁵⁷ commented on the controversy seen in the literature concerning EMG and muscle length. It was thought that one possible source of inconsistency centred around the fact that previous investigators had changed muscle length and the length of the lever arm simultaneously by moving the distal joint over which the studied muscles crossed. To avoid the extraneous variable of muscle leverage, Lunnen et al⁹ carried out a study on the biceps femoris muscle, wherein the distal joint angle, i.e. the knee joint angle, was held constant. The hip joint angle was altered so that maximal isometric contractions were made at four different angles, while the biceps femoris was monitored by surface EMG. Results showed that at the shortest length of the muscle, i.e. with the subjects in the supine (0°) position, the maximal torque generated was significantly less than at 90° and 135° of hip flexion, i.e. when the muscle was elongated. Conversely, for the same maximum efforts, statistical analysis demonstrated that the least IEMG generated, at 135° , was significantly less than that generated at 0° and 45° angles of hip flexion.⁵⁷

Thus, the majority of literature has supported the concept that heightened IEMG amplitude accompanies shorter muscle lengths, in voluntarily contracting muscle, at various levels of contraction efforts. It must be noted

that, although the length of muscle alters the magnitude of EMG and its action potential counts, the proportionality between EMG and tension, whether linear or nonlinear at any given length of a muscle, remains intact.^{46,53,61} Hence, only the slope of the relationship changes, so that the slope decreases with increasing length when the EMG is plotted on the ordinate and the force is plotted on the abscissa.

Heckathorne and Childress⁵³ attributed the EMG-muscle length relationship to two main factors. Firstly, the individual sarcomeres which comprise the muscle fibres, are less capable mechanically of generating force at shorter lengths, following Blix's classical length-tension curve as explained by Ralston.⁵⁵ Secondly, the activation-contraction coupling becomes impaired so that a twitch induced by a motor unit action potential is of shorter duration, decaying more quickly at shorter muscle lengths. In order to create a given force at a relatively short muscle length, the activation system must compensate for the two impairments by increasing the amount of motor unit stimulation, thereby increasing the magnitude of the EMG.⁵³

In keeping with the well-known length-tension relationship of striated musculature, as a muscle is lengthened, the parallel elastic components are put on

stretch. These fibres will behave like an elastic band, increasing the passive component of total tension. If the overall muscle force were to remain constant, an increase in the passive component of total tension would permit a decrease in the developed or contractile force to take place. The decrease in contractile tension would be reflected in a diminished EMG, due to the reduction in the number of motor units firing.⁵⁷

The role of the Golgi tendon organs have been considered by different authors^{56,57,60} with respect to EMG reduction, as seen with lengthened muscle. Libet et al⁵⁶ compared EMG prior to and following anaesthetization of the muscle tendon afferents of the tibialis anterior and gastrocnemius muscles. They found that the anaesthetic was effective in eliminating much of the decrease in EMG amplitude that normally occurred with stretch of these muscles. It was concluded that the usual decrease in electrical activity with stretch depended on the inhibitory afferent impulses from the tendon. The fall in developed tension associated with the length-tension curve, at greater lengths of muscle, would theoretically augment the autogenetic inhibition perpetrated by the muscle tendon afferents.⁵⁶ The role of the autogenetic inhibitory response in normal submaximal brief contractions is likely much less than in maximal sustained efforts.⁵⁶

Kinesiological EMG of the Hamstrings and the Gastrocnemius Muscle

The hamstring muscle group has been examined by electromyography in a variety of activities and postures. Most often these investigations have been focussed on qualitative and temporal analyses, rather than quantitative interpretations. The observation of selective activity of the medial and lateral hamstrings has not been extensively investigated. The analysis of gait is one area in which the electrical activity of the hamstrings has been studied. Hamstring activity has been examined by EMG in standing,^{63,75} forward walking,^{18,62,65} backward walking,⁶⁷ forward running,⁶⁴ and stair climbing.¹⁸ A methodology for selecting representative muscles for EMG gait analyses has recently been reported.⁶⁸ In some studies, the electrical activity of the medial and lateral hamstrings were reported as a whole although having been detected using separate electrode placements. Battye and Joseph⁶⁵ asserted that during normal walking on a flat surface, the activity of the medial and lateral hamstrings was not substantially different and thus the results from these muscles were combined for purposes of analysis. Dubo et al⁶² and

Schwab et al⁶⁴ chose a representative muscle from the hamstring group in order to interpret the actions of the knee flexor muscles in forward walking,⁶² and running,⁶⁴ respectively. Kramer and Reid⁶⁷ positioned the surface electrodes so as to detect EMG activity for the hamstrings as a single entity by placing one electrode over the motor point of the semitendinosus and the other over the motor point of biceps femoris, long head.

Recently, Lyons and associates¹⁸ examined the electrical activity in several muscles of the thigh during level walking on the level at two speeds, and in stair walking. The investigators were able to distinguish selective roles for biceps femoris, long head, and for semimembranosus. During free velocity walking, both muscles became active in mid-swing, peaking upon 90% completion of the gait cycle. The semimembranosus activity then dropped to about 5% of its MVC (reference activity), whereas the electrical activity of the biceps femoris, long head, peaked again during the loading response, to reach 30% of its MVC. The difference between the proportion of activity, compared to MVC, of the muscles was thought to be related to their control of medial rotation at the knee joint. In an effort to guard against overstraining of the knee ligaments, muscular restraint was needed. Hence, the peak EMG activity

registered by the biceps femoris during the loading response suggested that its external rotatory leverage protected the knee, at which time the internal rotatory effect of the semimembranosus muscle was diminished.¹⁸

Earlier investigations were undertaken in an attempt to establish myoelectric activity of muscles which participate in several basic movements of the hip and knee. Wheatley and Jahnke⁷⁷ investigated tibial rotation with the subjects in supine lying with tibias at right angles to the femur, and legs supported by a cart. The hamstrings showed no increase in EMG activity either in medial rotation or lateral rotation of the thigh when the thigh was in flexion. However, when the thigh was extended, medial rotation of the thigh was accompanied by increased electrical activity in the semitendinosus, semimembranosus, gracilis, and tensor fasciae latae, whereas lateral thigh rotation was associated with increased activity in the gluteus maximus and biceps femoris.

Active flexion of the leg with the subjects standing or in prone, was associated, as expected, with activity in all of the hamstring muscles throughout range. The sartorius and gracilis entered into action near the 90° angle of knee flexion when the movement was gravity-resisted, and almost immediately upon commencement of the movement, i.e. from the position of knee extension, when external resistance was added.⁷⁷

Bierman and Ralston⁷⁶ emphasized the role of the hamstrings, represented in their study by the biceps femoris, as active antagonists to knee extension. This function was assumed to be related to protection of the knee in order to avoid overextension of the joint.

The actions of the biceps femoris, long head and short head were recently studied using coaxial needle electrodes, by Furlani and associates¹⁷, during a variety of active movements performed by 20 healthy male subjects. During lateral rotation of the leg, with the knee flexed, the long head and the short head of biceps femoris were electrically active in only slightly more than 50 percent of subjects and therefore it was deduced that the muscle was not required for the performance of this movement. In contrast, both heads of the muscle were active in knee flexion.¹⁷

Snyder and Forward⁷⁸ examined the electromyographic activity of several thigh muscles, including the biceps femoris and medial hamstrings taken collectively during the performance of active knee flexion and extension in the diagonal and sagittal planes of movement. The study was constructed to test the value of proprioceptive neuromuscular facilitation (PNF) type movement patterns involving the knee and hip. The diagonal plane movement involved the combination of knee flexion, internal

rotation of the thigh and slight hip abduction, beginning at a knee angle of 120° moving into knee extension, external rotation of the thigh and slight adduction, with 0° of knee flexion, i.e. full extension. The subjects were seated with their legs hanging freely prior to commencement of the movement patterns. The sagittal plane movement traversed the same range of knee flexion, but the femur rested in mid-position. Recordings of EMG activity were reported for the 0° and 120° angles of knee range, for both movement patterns. The amount of rotation of the tibia on the femur was considered by the writers to be minimal and was not analyzed for this reason. This assumption has been proven incorrect.^{8-13,15,16} The 120° position of knee flexion for the diagonal pattern appeared to be conducive to gravity-assisted internal tibial rotation. Of special interest was the segment of both movement patterns which involved an active excursion into knee flexion against gravity resistance i.e., the 90° to 120° segment. The biceps femoris muscle was found to be equally active in both movement patterns at the 120° position, whereas the medial hamstrings were more active in the sagittal plane at the 120° angle, during slow knee flexion. The authors concluded that sagittal plane movements were more successful in activating the muscles examined than were diagonal plane movements.⁷⁸

Miwa and associates⁶⁰ studied several biarticular muscles including the biceps brachii, the biceps femoris, semitendinosus, and the gastrocnemius muscles. The writers theorized that because the biceps brachii and likewise the hamstring muscles run parallel to the humerus and femur respectively, the efficiency of the particular muscle examined to flex the joint in question, i.e. the elbow or knee, was least when the joint was fully extended. Consequently, the most vivid EMG activity would hypothetically occur at full extension of the joint, when more muscular effort would be required to promote a turning effect at the joint. Experimentally, however the greatest amount of electrical activity occurred further into flexion of the joint. This factor was true of all the muscles mentioned above. The investigators examined the gastrocnemius, as an assistive flexor of the knee, and determined its pattern to be similar to that of semitendinosus, thus refuting the suggestion that assistive flexors of this joint might act violently from full extension to about 160° at which time the prime flexors would begin to act. The investigators suggested that there may be differences in the amount of electrical activity in a tensed muscle which is lengthened compared to when it is in a shortened state, even though equal tensions are generated at both lengths. Comparisons of

EMG activity in isotonic and light isometrically-resisted tests at 110° and 70° of knee flexion, consistently demonstrated higher EMG at the shorter length, i.e. at 70° of knee flexion.⁶⁰ Full extension was considered to be 180° .

The findings of Lunnen et al⁵⁷ concurred with those of Miwa et al⁶⁰ regarding the IEMG-muscle length relationship, and, as reported in an earlier section, had the added advantage of eliminating the contaminating variable of muscle lever changes which accompany muscle length changes when the distal joint of a two-joint muscle is moved. By removing this variable in the case of the biceps femoris muscle, an uncluttered view of the IEMG muscle length relation was seen in the isometric condition during maximal efforts. The same study also demonstrated that when the IEMG was held by the subjects, at a constant level for the four angles tested, more torque was required to maintain the IEMG level when the muscle was in its lengthened state. Conversely, when a constant submaximal torque was maintained, less IEMG was registered at the lengthened state of the muscle, compared to the shorter lengths. As pointed out by Miwa et al⁶⁰ and by Lunnen and associates,⁵⁷ of vital importance is the quantitative relationship between the contributions of the passive elastic component and active contractile components of the

total tension or torque measured in a muscle or muscles. Also, the effects of neurophysiological phenomena, as discussed previously (see EMG - Muscle Length section), must be included in the overall scenario, in order to comprehend the complexity of the interplay between various components which modify the relationship between the EMG and tension.

A recent study by Leonel and Furlani⁸⁰ dealt with the selectivity of the medial and lateral hamstring muscles during free and resisted bicycle pedaling. The segment of the motion examined included knee flexion from near full knee extension, i.e. 0° of knee flexion, to approximately 120° of flexion. The subjects performed 3 test movements during this segment (1) a normal ankle position combined with knee flexion, (2) eversion of the ankle and (3) inversion of the ankle. When knee flexion was carried out in combination with eversion of the foot, the biceps femoris was found to be frequently inactive. With the foot everted, a concomitant internal rotation of the tibia was assumed to have occurred, thus causing cessation of activity from this lateral rotator of the tibia. Conversely, with the foot in inversion, the biceps femoris was active in all subjects. In contrast, during the initial 20° of knee flexion combined with inversion, the semimembranosus and semitendinosus muscles were silent

except for two instances, and the semimembranosus was virtually inactive throughout total range. Thus, with the foot everted only the medial hamstrings were effective, and during inversion the biceps femoris was most active, followed by the semitendinosus in later ranges. Normal foot position combined with knee flexion saw participation throughout range of all three hamstring muscles.

The main role of the gastrocnemius muscle, in concert with the soleus muscle, is to plantar flex the ankle joint against resistance, with a secondary function of knee flexion under certain circumstances.^{1,60,75,81-84}

Basmajian⁸¹ stated that the fibres of the muscle are very short, so that it is not able to simultaneously flex the knee joint and plantar flex the ankle. Hollinshead⁸³ explained that because the gastrocnemius crosses the knee joint it will flex the knee when it acts upon a leg that is not supporting weight. However, when the leg does support weight, contraction of either component of the triceps surae, i.e. the soleus or medial and lateral heads of the gastrocnemius, resists dorsiflexion of the ankle, which consequently prevents knee flexion during standing.

The electromyographic activity of the gastrocnemius muscle as a flexor of the knee has been of interest with regards to temporal and qualitative analyses of gait, and was found to function in promoting ankle plantar flexion

during the stance phase of gait.^{18,62,64,67,68} The role of gastrocnemius as an assistive flexor in backward walking was conjectured by Kramer and Reid⁶⁷ in their cinematographic and EMG analysis of backward walking. Hof and Van Den Berg⁷⁹ studied the relation between external torque and the weighted sum of the EMG's of the human triceps surae, and also tested the gastrocnemius in its plantar flexion function and established that the IEMG of each individual muscle comprising the triceps surae, was linearly proportional to the torque it develops.

Liberson et al⁵⁴ determined, for maximal isometric efforts of the gastrocnemius muscle, the presence of greater EMG activity when the muscle was in a relatively shortened position, supporting the findings of previous authors as to the IEMG-length relationship of striated muscles. They attributed the results, in part, to artifact resulting from the gross change in muscle contour when contracted in the shortened position. The gastrocnemius was contracted isometrically by attempted plantar flexion.⁵⁴

Thus, quantitative electromyographic investigations of the gastrocnemius have not considered this muscle in its role as a knee flexor. Judging from EMG studies of the muscle in its role as a plantar flexor, the muscle appears to follow the EMG-tension and EMG muscle length associations observed in other striated muscles.

Isokinetic Exercise

The distinctive feature of isokinetic exercise is that the speed of the movement, of the effort arm, is held constant by a special device,²³ so that the speed of muscular performance is controlled.⁸⁵ Consequently, resistance is in direct ratio to the varying force applied through the full course of a movement.^{23,85} Acceleration of the moving part is not permitted by the mechanical resistive device. Because energy cannot be dissipated by acceleration, it completely converts to a resisting force.⁸⁵

During isokinetic work, the resistance is least at the extremes of muscle range, where the mechanical advantage of the muscle is also least. This circumstance contrasts that found in isotonic exercise with a constant resistance, in which the resistance has its greatest mechanical advantage on the muscle at the extremes of muscle range. Thus, the resistance is greatest at these extremes. Nearer to mid-range of movement, the mechanical advantage of the muscle is greatest. Consequently, the resistance is proportionately less.^{19,85} The underlying advantage, therefore, of isokinetic exercise is that the muscle can work at its maximum capacity throughout its entire working range.

In addition to its utilization as an exercise device the isokinetic dynamometer can be used to measure muscle performance.²³ The dynamometer is a variable speed control device which permits dynamic torsional forces to be recorded at predetermined velocities, including zero velocity, throughout joint range. The torque applied to the input shaft can then be registered.¹⁶

The relationship of knee flexor torque to angle of knee flexion has been studied with regard to isokinetic exercise.^{24,86,88,90} Investigations of maximum voluntary isometric efforts⁹¹⁻⁹³ found that the shape of the torque curve depended largely upon the hip angle of the subject. When maximal efforts were performed from the prone lying position, with the hip angle at 0°, the greatest torques were recorded very early in range, being located at or near 0°, i.e., near full extension. Conversely, maximal efforts produced with the subjects sitting produced peak torque values later in knee flexion range, from 60°, ⁹³ to approximately 30°. ^{91,92} These isometric investigations provided a foundation for comparing isokinetic torque patterns.

Scudder⁸⁸ conducted isokinetic knee flexor torque analyses on a sample of healthy young males. The subjects were seated, with the hips angled at 70°, from the 0° supine lying reference position. When the velocity was

set at $18^{\circ}/s$, peak torque achieved 90% of the isometric value, and the location of peak torque did not vary substantially from that of the peak isometric value.

Moffroid et al⁸⁶ employed a sample consisting of 48 females and 12 males. Isokinetic knee flexion was performed with maximal effort from the sitting posture. The hip angle was not reported. At a constant velocity of $22^{\circ}/s$, maximum torque occurred at 34° of knee flexion, and the torque pattern was similar to that found previously by Williams and Stutzman⁹¹ who had tested isometrically.

Knapik and associates⁹⁰ compared isokinetic knee flexor torque of normal young women and men. Several velocities of contraction were used. For the females, maximum torque was located at 20° at $0^{\circ}/s$ (isometric) and at $36^{\circ}/s$. Peak torque for the men occurred at 20° of knee flexion when the velocity was $20^{\circ}/s$, and at the 30° angle for a velocity of $36^{\circ}/s$. Houtz et al⁹³ located peak torque at 60° of flexion, also in a male sample. Consequently, for therapeutic purposes, an initial assessment should be conducted to establish the unique torque pattern of the patient, prior to implementation of a rehabilitative program.⁹⁰

A typical isokinetic torque pattern for the knee flexors is illustrated in Figure 2.

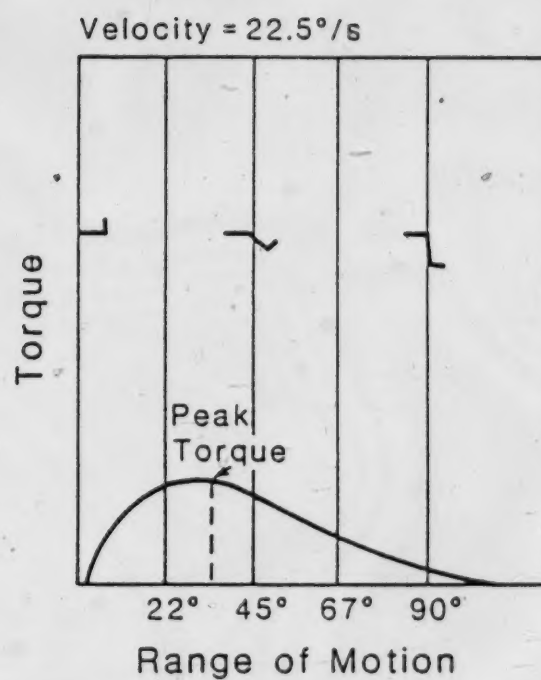


Figure 2. A typical isokinetic torque pattern for the movement of knee flexion (modified from Moffroid et al., 1959)

Isokinetic dynamometry has been applied also to the movements of tibial rotation.^{10,11,16} All of these studies were designed so that the angle of knee flexion remained static during the rotations of the tibia. Various adaptations of the Cybex II isokinetic dynamometer were designed by the different authors to allow recording of tibial rotation torque throughout available range of motion.

Osternig et al¹⁶ devised a technique for the simultaneous recording of angular displacement and torque for tibial rotation. The same investigative team conducted a subsequent study¹¹ using male subjects in normal health. Maximal voluntary contractions were performed into both external and internal tibial rotation, at a velocity of 15°/s. Results indicated that no statistically significant differences existed between right and left lower limbs, for total range of motion available. Secondly, no significant differences were evident in torque values between right and left limbs at any angle of tibial rotation compared. These findings were the same when the knee was held in 45° of flexion and in 90° of flexion. The mean differences in recorded torque between the external rotators and internal rotators were less than 10% at all angles of tibial rotation. Mean active range of tibial rotation was 12% to 15% more with

the knee held at 90° compared to the 45° angle. In addition, torque values measured when the knee was placed in the 90° angle were consistently higher than those recorded with the knee positioned at the 45° angle.¹¹

A recent study by Hester and Falkel¹⁰ also employed isokinetic dynamometry to establish norms for right and left legs in active tibial rotation, with the knee held at the 90° position. Results indicated that mean peak torque was slightly higher in maximal efforts into external rotation, compared to internal rotation. The right leg demonstrated minimally higher torque values. None of these results were statistically significant and thus were consistent with the previous findings of Osternig and associates.¹⁸

Recent publications^{19,20} advocated exercises consisting of the combination of isokinetically-resisted knee flexion and tibial rotation in cases of rotational instabilities of the knee. The combination of knee flexion and internal tibial rotation was designed to emphasize the activity of the medial hamstrings for the rehabilitation of anteromedial instabilities,^{19,20} posterolateral instabilities,¹⁹ and medial collateral ligament strains.¹⁹ The combination of knee flexion and lateral rotation of the tibia was intended to isolate the biceps femoris for treatment of anterolateral instabilities of the knee.^{19,20}

The published literature indicates that although isokinetic torque curves have been reported for the knee flexor muscles,^{85,88,90} and recently for the tibial rotators,^{10,11,16} no isokinetic data has been made available to establish the torque pattern concomitant with combinations of knee flexion and tibial rotation. Recently, authors^{19,20} have suggested such combination movements acting on the assumption that by performing these exercises the medial and lateral hamstring muscles could be made to work selectively. Hence, their roles as rotatory stabilizers of the knee could be more effectively addressed in a rehabilitative context. The present study was designed, in part, to provide data on the torque pattern and the relative magnitudes of torque involved with the performance of the described exercise combinations.

Conclusions

Electromyography has frequently been used as an investigative tool to enhance the kinesiological evaluation of skeletal muscles. IEMG has facilitated the quantitative analysis of muscular contractions. Several researchers have studied the relationship between IEMG and tension and have found linear and nonlinear relations for

various muscles and muscle groups, contingent on certain specified experimental conditions. The exact nature of the IEMG tension relationship remains highly controversial and depends on many factors.

The length of a muscle has been shown to affect the IEMG-tension ratio. Muscular fatigue has also been observed to affect this relationship. An additional influential variable is that of muscle leverage. The major effects of these variables have been discussed.

Isokinetic dynamometry has become a popular and effective method of evaluating muscular strength. Torque patterns have been reported for knee flexion and tibial rotation, but not for combinations of these movements. Such combinations have been suggested in rehabilitative programs.

The present investigation was designed in order to provide a kinesiological evaluation of the hamstring muscles, and secondarily the gastrocnemius muscle, during isokinetically-resisted movement patterns involving three combinations of knee flexion and tibial rotation. Quantitative electromyography and torque data collected during these movement patterns would conceivably lead to an enhanced understanding of the potential value of each combination, applied to a rehabilitative setting. The most judicious application of these exercises would then be possible.

CHAPTER THREE

MATERIALS AND METHODS

Subjects

Nineteen females in the age range of 21 to 35 years were included in the experiment. There were no restrictions concerning fitness level. None of the subjects reported a history of trauma to the right lower limb or to the lower spine of sufficient severity to have required medical treatment or to interfere with the performance of tasks required of them during the present study. A sample consent form is displayed as Appendix 1.

Instrumentation

A Leaf Electronics System VII Electromyograph Channel Amplifier* was employed to detect electrical activity in the hamstring and gastrocnemius muscles. The integrated output mode was used to facilitate quantification of results. The integrator smoothing time constant for each channel was set at 250 ms. The artifact suppression was set at the 60 + 120 Hz setting for all subjects. The

* Leaf Electronics System VII 4-Channel Electromyograph and Amplifier; Leaf Electronics Ltd., Suite 102, 11804 - 124 Street, Edmonton, Alberta, T5L 0M3.

three channels of the Leaf Electronics System Electromyograph which were used to amplify the electrical activity of the muscle groups were each connected to the bioelectric amplifiers of the Hewlett Packard 7754A Recorder.* The integrated and amplified myoelectrical signals were then recorded on the thermal pen recorder system for each IEMG channel. The gain for each channel was set at 0.2 volts per 40 divisions of graph paper. The upper cutoff frequency selected was 1000 Hz and the lower cutoff frequency was 0.05 Hz. The chart speed was set at $2.5\text{mm}\cdot\text{s}^{-1}$ for the reference activity and at $10.0\text{mm}\cdot\text{s}^{-1}$ for the isokinetic test movements.

The leads for the surface IEMG electrodes were connected to the remote transponder unit of the Leaf Electronics System VII Electromyograph. The selective band filter was used following the manufacturer's advice,⁹⁴ in order to filter 60 Hz interference from the atmosphere. From the remote transponder the electromyographic signal was transmitted through an input cable to the main EMG unit, and then to the Hewlett Packard system as previously described.

* Hewlett-Packard 4-Channel Thermal Tip Recorder; Hewlett-Packard (Canada) Ltd., 1162A - 168 Street, Edmonton, Alberta, T5M 3T9.

Accurate measurement of total torque production during reference activities and subsequent test movements was made possible by employing a Cybex II isokinetic dynamometer. In order to synchronize the torque recordings with the IEMG registrations the fourth Hewlett Packard bioelectric amplifier and recording channel was used to record torque. A gain setting of 5.0 volts per 50 divisions of graph paper was used. The angular velocity setting for the isokinetic test repetitions was 3 RPM.

In an effort to accurately record knee flexion angles on the same channel as torque, a microswitch trigger mechanism* was afixed to the central axis of the Cybex II input shaft (Plate 5). Two metal brackets collared the central axis and were angled at 60° with respect to each other. The first bracket was arranged to engage the microswitch trigger at the 30° angle of knee flexion. The trigger mechanism caused an immediate deflection of the pen on the torque channel of the recorder. A second pen deflection occurred at the 90° angle, when the second bracket engaged the trigger. The speed of pen deflection was extremely high, thereby sacrificing a negligible amount of torque recording.

*E23-00k microswitch; Cherry Electronics Products, Waukegan, Illinois.

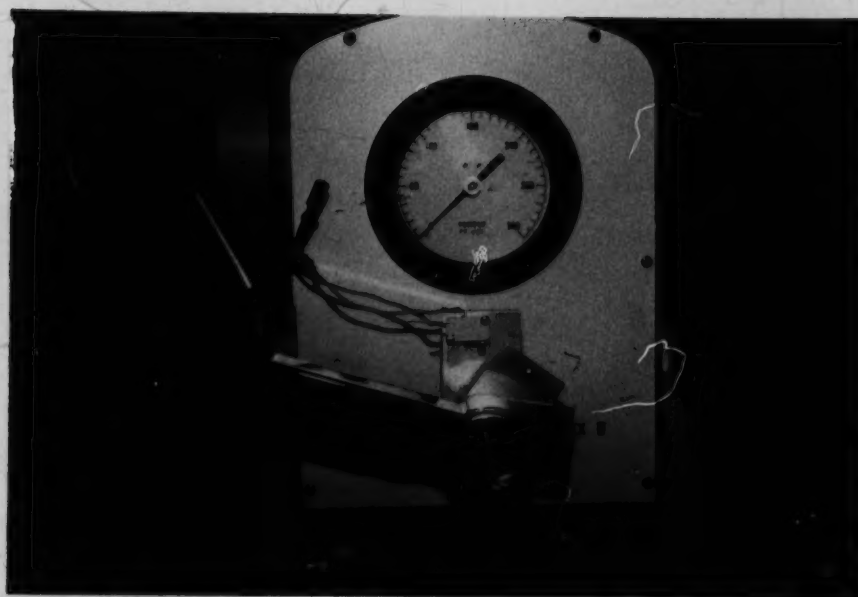


Plate 5. The E23-00K microswitch and trigger mechanism
affixed to the Cybex II Dynamometer

The placement of the surface EMG electrodes followed the practice of previous investigators,^{18,61,74,95,96} who located the electrodes over the motor point of the selected muscle. Standard reference texts⁹⁷⁻⁹⁹ were used to find the motor points of the semitendinosus and biceps femoris, long head, muscles. These muscles have previously been used in surface EMG investigation to represent the medial and lateral hamstring muscle groups, respectively.⁶⁷ The motor point is situated within the muscle where a great density of terminal motor endplates is found near the muscle's surface.⁹⁹ A zone encompassing a low threshold of neural excitability surrounds the motor point, and the skin is very sensitive to electrical stimulation by Faradic-type currents.⁹⁹ Thus, by first estimating the location of the motor point, using the standard references⁹⁷⁻⁹⁹ as a guide, followed by visual inspection and palpation of the muscle belly, for purposes of cross-reference, each muscle was faradically stimulated using a Teca Electrotherapeutic Stimulator*. The region of the muscle which was stimulated to contract by the lowest intensity of faradic current, was considered to be the motor point for that muscle. In the described manner

*Teca Corporation Electrotherapeutic Stimulator, Serial number SP5/T. Three Campus Drive, Pleasantville, N.Y. 10570.

the motor points for the semitendinosus and biceps femoris were established.

The Leaf Electronics System VII Electromyograph main unit and transponder unit, and the Hewlett Packard recorder system were calibrated prior to the initiation of data collection and again following the data collection segment of the thesis. The Cybex II isokinetic dynamometer was calibrated prior to and following data collection for each subject. Calibration procedures and data are presented in Appendix 2.

The present research design required accurate determination of knee joint angles. Without the advantages of radiography, it was necessary to estimate the line of the femoral shaft. This estimation was accomplished by visual and palpational means. Using the greater trochanter as a landmark, the length of the shaft of the femur was palpated. A straight line was then drawn on the skin to represent the femur. This line was orientated in a parallel relationship with a horizontally situated spirit level, when the subject had taken up the slack in the stabilization apparatus by maximally contracting the knee flexors, with isometric resistance provided by the stationary dynamometer input shaft. The shaft of the tibia was then aligned to the horizontal plane by again employing a spirit level. This procedure

was also conducted during a strong isometric knee flexor contraction. The alignment of the femur was then reassessed. Deviation from horizontal was corrected by adjusting the thigh strap to align the femur, and by moving the input shaft to align the tibia. The horizontal position was defined as 0° of knee flexion.

Having established the 0° position of the knee joint, it was necessary to implement an accurate method of measuring angular displacement of the knee joint. Many studies have endeavored to establish the most valid and reliable means of detecting angular displacement, in a clinical setting.

Pendular goniometry has been stated to have certain practical advantages over standard goniometers. Firstly, location of the joint axis is not required, thereby eliminating a potential source of measurement error.¹⁰⁰ Secondly, by affixing the pendulum goniometer to the segment being moved, the investigator's hands are free to perform other tasks.¹⁰ Leighton¹⁰² reported correlation coefficients of between 0.913 and 0.996 in a reliability study of joint angles for 120 boys, in a project conducted to test a prototype of the more sophisticated flexometer bearing his name. Recent studies^{101,103} reported high reliability coefficients for the Leighton flexometer¹⁰¹

and also for a less sophisticated pendular goniometer*.¹⁰³ The first study¹⁰³ was performed to measure test-retest reliability of an active knee extension. One examiner performed all measurements for each subject. The intrarater correlation coefficient was 0.99. The second study¹⁰¹ compared the reliabilities of three different instruments including a standard 360° protractor type goniometer, a Leighton flexometer, and a tape measure, from which trigonometric calculations were made. Intrasection reliabilities were excellent for all three methods, and was $r_r = 0.97$ for the Leighton flexometer. The flexometer was determined to be as reliable as the goniometer for intrasection and interseccion measurements of passive straight leg raising.¹⁰¹

For the present study, the OB Vinklematare "Myrin" pendulum goniometer** was used for measurement of the knee joint movement in the sagittal plane. This goniometer was tested for reliability as documented in Appendix 3. The reliability coefficient was $r_r = 0.99$.

The pendulum goniometer was affixed using adhesive tape and a velcro strap, to the lateral aspect of the

*Phillips Podiatric Medical Center, 252612 Ave. S., Great Falls, MT 59405.

**O.B. Vinklmatare "Myrin", O.B. Rehab-Produkter, 10051 Stockholm, Sweden.

subject's calf. It was aligned parallel with a previously drawn line which approximated the longitudinal axis of the tibial shaft. Maintenance of this parallel relationship ensured that subsequent angular measurements were consistent throughout the data collection procedures (Plate 6). The dial of the goniometer was orientated so that the gravity-dependent arrow pointed to 0° on the dial, with the knee at the established 0° position. The brackets used to trigger the microswitch mechanism, were then positioned so that, with the subject maximally contracting, the microswitch would be triggered at 30° of knee flexion, and then at 90° .

The Experimental Procedure

Practice session

Each subject underwent a practice session a minimum of two days and a maximum of seven days prior to test day. The minimum time period was set in order to permit full recovery from muscular fatigue incurred during the practice session.¹²⁸ The maximum interval was established in an effort to decrease the likelihood of a tendency for the subjects to lose the benefit of the familiarization session.¹²⁹ The practice session was needed for two main reasons. Firstly, the time required for motor point



Plate 6. The pendulum goniometer as used in the experiment

location and for estimation of the lines of the femoral and tibial shafts would have created an unreasonably long test day session, and therefore these determinations were carried out during the practice session. Secondly, it was hoped that by familiarizing each subject with the exact conditions of the experiment, greater consistencey of performance could be achieved.

In addition to the location and marking of motor points of the biceps femoris, long head, and the semitendinosus, an appropriate location had to be determined to represent the whole gastrocnemius complex for EMG detection. A frequently used procedure was to palpate a muscle to locate the region of greatest bulk, and to place the surface electrodes there.^{3,37} For the present study, palpation determined the separation of medial and lateral heads of the gastrocnemius. With the subject then performing manually resisted plantar flexion, the area of greatest bulk was confirmed. Using visual and palpational information, the point for electrode placement was ascertained and marked.

Following the location and marking of the visual landmarks, each subject was instructed in the test day procedure. First, three submaximal and then three maximal isometric contractions were performed by the knee flexors, at the 30° angle of knee flexion. All stabilization

procedures and verbal encouragements were provided in order to simulate test conditions. The participants then performed the isokinetic test movements. At least one submaximal and one maximal effort in each test position was performed. Most subjects performed additional repetitions, at their own discretion or on request of the investigator, if any difficulty was demonstrated with a specific test position or movement sequence.

The term submaximal was described to the subjects as a contractile effort which was subjectively perceived to be approximately 50% of their maximum capability.

Test Day Procedure

Electromyography.

The subject was first positioned in prone lying. Preparation of the skin involved briskly rubbing the preshaved skin with rubbing alcohol, in order to remove surface substances such as oils and dead skin which otherwise would serve to increase the electrical impedance between the skin surface and the surface electrodes.³ Conductivity gel was applied to the electrodes so that the central well of the disc was filled. A thin layer of gel was spread over the surface of the disc, in order to improve the electrical conductivity between the skin and

each electrode.^{3,94} The active electrodes were placed longitudinally over the muscle belly, i.e. in a parallel relationship to the muscle fibres. The electrode pair straddled the pre-established pen mark, at equal distances from the mark. The interelectrode distance was 2 cm, measured edge to edge. A third disc, the ground electrode, was placed approximately 4 cm from the pen mark, but was not otherwise restricted as to location. All electrodes were secured firmly to the skin surface with adhesive strips. The procedure was implemented for the biceps femoris, long head, the semitendinosus, and the gastrocnemius muscle. Stainless steel surface electrodes were used.⁶⁷ The subjects then were situated in a sitting position on the Cybex II table, at which time the electrode leads were connected to the transponder unit of the Leaf Electronics System Electromyograph.

Seating Specifications.

In formulating the present research design it was decided to employ a set-up which was similar to the clinical situation. It was thought that by doing so, the results would be more readily transferable to a clinical setting. Further, it was postulated that the most desirable subject position for the present experiment would be that in which the torque capability throughout knee flexion range was maximized.

Several studies^{57,92,93} examined the effect of hip angle on knee flexor torque. All of these investigations showed that optimal torque values were derived when the subjects were seated, rather than in prone or supine lying. The isometric mode of exercise was employed in these studies. A study by Lunnen et al⁵⁷ found maximal torque values for isometric knee flexion to occur when the subject was in a forward leaning position at a hip angle of 135°. However, no statistical significance was present between the torque produced in this position and that developed at the 90° hip angle, i.e. with the trunk vertical. In their study, Walmsley and Yang⁹² maintained the hip at an 80° angle for seated knee flexor efforts. Houtz and associates⁹³ did not provide external stabilization of the trunk.

Therefore, based on the considerations as presented in the literature, the sitting posture was chosen for the present experiment. The Cybex exercise table was adjusted so that the back rest was angled at 75°. This arrangement proved to be comfortable for the participants, and facilitated optimal knee flexor torque capability.

An important consideration related to seating specifications was the consistency of pressure on the surface electrodes during isokinetic test repetitions. Normally, with the subject seated, the weight of the lower

limb would cause an increase in pressure between the surface EMG electrodes for the lateral and medial hamstrings, and the skin surface. In addition, it would be expected that the soft tissue interposed between the electrodes and the muscles themselves would compress, thereby decreasing the distance between the electrodes and the muscles. In isokinetically-resisted exercise, the possibility exists that the external pressure acting on the electrodes would change unpredictably as the range of motion progressed. The pressure fluctuation would have the effect of altering the pick-up area of the electrodes. For this reason, the IEMG values would not be reliable. To avoid this limitation, the height of the posterior extent of the seat was elevated, thus allowing the thigh to remain clear of the table during all test performances (Plate 7).

It was observed during preliminary testing that the test limb would usually come in contact with the anterior edge of the testing table before the angle of 90° knee flexion was reached. This observation prompted a further modification of the seating arrangement. Plywood sheets were placed against the back rest. Three sheets 2 cm thick were normally required. This adjustment had the effect of shifting the knee axis forward so that a minimum of 100° of knee flexion was available to the subject. In



Plate 7. The experimental setting

this manner, full range maximal isokinetic efforts were accommodated by the experimental design.

The Starting Position.

The subject assumed the sitting position, being careful to avoid disturbing the electrodes. The appropriate lead connections were made to the transponder unit, to the electromyograph and to the recorder. The subject was secured using shoulder and waist restraints, ensuring that the latter was positioned at the level of the anterior superior iliac spines, thus strongly inhibiting the tendency of the pelvis to move anteriorly during maximal contractions. The shoulder straps were tightened to subject tolerance, in an effort to prevent hip angle changes due to trunk movement in the sagittal plane. The thigh strap was then fastened just proximal to the knee joint line, and was effective in preventing superior excursion of the thigh above the horizontal during test contractions. The right tibia was then secured to the Cybex II input shaft by using the appropriate foot extension apparatus. The leg was restrained by a velcro strap just above the ankle joint. An attempt was made to avoid pressure on the belly of the gastrocnemius by adjusting the padded rest of the foot attachment to its most distal setting, maintaining the intermalleolar line as the most distal setting allowed.

The thigh and leg were adjusted to the horizontal 0° position. The pendulum goniometer was then affixed to the lateral aspect of the tibia. The bracket adjustments were made to ensure triggering of the microswitch at the predetermined angles. The knee axis was aligned with the axis of the input shaft, while the subject produced a strong isometric contraction. A subsequent isokinetic effort confirmed that proper alignment was maintained throughout test range. The subject was instructed to perform all contractions while her arms were folded across her trunk.

The torque dial of the dynamometer was covered so that concurrent visual feedback was not possible. The chart recorder was in partial view but the subjects were instructed not to focus on the recorder during test efforts. Subject compliance was excellent in this regard. Verbal encouragement was selected as the mode of motivation for the participants. Armstrong¹⁰⁴ compared methods of verbal motivation applied to subjects performing maximal isokinetic efforts. Peer motivation was compared to tape-recorded encouragements to assess their relative effectiveness on torque production during test efforts. The method of peer motivation proved to be the superior motivational method. Thus, for the present study, the investigator provided continual verbal

encouragement, as consistent in voice level as possible, to each subject during all isometric and isokinetic test efforts.

Warm-up Procedure.

Mawdsley and Knapik¹⁰⁵ showed that if subjects are to be tested in one session, at least one maximal contraction should be performed before recording criterion strength scores to encourage replicable findings. They also stated that "safety considerations" may dictate the need for one or two submaximal contractions before actual testing is conducted. Mawdsley and Croft¹⁰⁶ investigated the effect of preliminary submaximal isokinetic contractions on subsequent maximal torque values, during knee extensor contractions. Inexperienced subjects were used. Results indicated that three preliminary submaximal contractions did not facilitate consistency in the torque magnitudes registered during the maximal contractions which followed. An initial maximal effort was required before succeeding maximal torque readings demonstrated stability. However, the submaximal practice efforts were effective in diminishing discomfort otherwise experienced by the subjects during the maximal contractions. Johnson and Siegel¹⁰⁷ concluded from their study of 40 female volunteers that in measuring the torque of isokinetic

efforts, a protocol which provided for three submaximal trials followed by three maximal warm-up contractions, was essential before stable measures could be achieved.

The present study utilized the more conservative regimen proposed by Johnson and Siegel¹⁰⁷ as it was essential to obtain reliable measurements. Therefore, the warm-up session consisted of three submaximal contractions followed by three maximal efforts first performed isometrically at the 30° angle of knee flexion, and then carried out isokinetically. One major consideration as a consequence of the present research design, was the possibility of muscular fatigue. The effect of fatigue on the IEMG-tension relationship was previously described. Hence, to reduce the possible effect of fatigue on the results, a minimum number of test repetitions was desired. Therefore, only one submaximal contraction and one maximal warm-up effort were requested for each isokinetic test movement combination (normal rotation; external rotation; internal rotation), in addition to the three submaximal and three maximal warm-up contractions performed isometrically in normal rotation. A total of 12 warm-up efforts were performed prior to data collection: six in the isometric mode, and six in the isokinetic mode. Each submaximal effort was followed by a 30 second rest interval, and each maximal effort was succeeded by a

one minute interval. Verbal encouragement accompanied the maximal contractions.

Test Repetitions

1. Isometric. Conventionally, electromyographic data have been expressed as a percentage of a pre-established reference activity.^{3,30} Often the IEMG recorded during a maximal isometric contraction is designated as the reference activity. Other IEMG activity from the same muscle is quantified as a proportion of the reference IEMG. The present investigation designated the reference activity to be the IEMG amplitude recorded during an isometric maximal voluntary contraction (MVC) when the knee was flexed at 30°. The tibia was in the position of normal rotation. Torque data were also recorded as percentages of the torque registered during the reference activity.

The subject was requested to assume the appropriate starting position. The knee joint was stationed at the 30° angle, the tibia was in normal rotation, and the subject held her arms folded across her chest. She was instructed to gradually increase the isometric effort to maximal as the investigator counted aloud "one thousand, two thousand". The slow increase to maximal resistance was included in an effort to avoid the "overshoot"

phenomenon previously described related to isokinetic dynamometry, in ballistic efforts.¹³⁰ The subject maintained the MVC for approximately five seconds or until the amplitude of IEMG as traced on the Hewlett Packard recorder was observed to markedly decline. The verbal cues and encouragement continued to the cessation of each repetition and were stated in the following sequence: "one thousand, two thousand, now you're there, push, keep pushing...now relax". These words were spoken in a firm, controlled voice. Three repetitions were completed, separated by one minute rest periods. A three minute interval was allotted following the final isometric MVC, and prior to the isokinetic test repetitions.

2. Isokinetic. The subjects performed three isokinetically-resisted maximal efforts into knee flexion, in each of the three test positions: normal rotation, external rotation, and internal rotation of the tibia. The order of performance was determined by random assignment. The velocity of contraction was set at 18°/s. This relatively slow velocity had the advantage of allowing the subjects to achieve a maximal isokinetic effort in earlier range of motion than would have been possible with higher velocities. Prior to each test contraction the investigator assisted the subject in ~~attaining the horizontal starting position~~, in order to

prevent undue overall fatigue from occurring. The investigator next directed the subject to contract the hip flexors and knee extensors with sufficient force to maintain the starting position without the benefit of external assistance. This very brief contraction enabled the investigator to quickly remove his hand from beneath the input shaft of the dynamometer, thus erasing potential interference during the subsequent test contraction. At the verbal command "Go!", the participant endeavored to achieve a maximal contraction against the moving input shaft as quickly as possible. She was expected to maintain a maximal contraction throughout the entire test range of motion. The subject was urged to "Keep pushing as hard as you can! Don't quit!" Each contraction was followed by a one minute rest period. A total of nine maximal contractions were performed by each participant in the isokinetic test mode, i.e. three in each test position.

A time sequence flow chart of the experimental proceedings is shown in Figure 3.

The chart speed used during the recording of isometric efforts was $2.5\text{mm}\cdot\text{s}^{-1}$ and for isokinetic test repetitions, $10\text{mm}\cdot\text{s}^{-1}$.

TIME SEQUENCE

ACTIVITY

45 min

Positioning and securing of electrodes at motor points
 Positioning of subject into starting position
 Positioning of pendular goniometer and subsequent orientation of microswitch brackets (to trigger at 30° and 90°)
 IEMG gain adjustments

WARM-UP

9 min

Three submaximal isometric contractions in normal position (30 s rest between repetitions)
 Three maximal isometric contractions in normal position (1 min rest between repetitions)
 Three submaximal isokinetic contractions: one in each position (30 s rest between repetitions)
 Three maximal isokinetic contractions: one in each position (1 min rest between repetitions)

3 min

TEST (DATA COLLECTION)

2.25 min

Three maximal isometric contractions in position (1 min rest between repetitions)

3 min

8.75 min

Nine maximal isokinetic contractions: Three repetitions in each of the three positions defined (1 min rest between repetitions)

TOTAL TIME: Approximately 71 min

Figure 3. Time sequence flow chart of the experiment

Wire and Surface IEMG Comparison

Previous studies^{18,67,77,78} have employed surface EMG to differentiate the activity evoked in the medial and lateral hamstring muscles, for a variety of movements. The close proximity of the biceps femoris, longhead, and the semitendinosus muscles led the investigator to determine, in 1 subject, the existence, if any, of "crosstalk" between the medial and lateral hamstring muscles. The method employed was similar to that described by previous authors,⁷⁹ and consisted of simultaneously recording from both muscle groups using surface and wire electromyography. Details are provided in Appendix 5.

Data Presentation and Analysis

The analysis of data was based on the pen recordings of IEMG and torque during test repetitions (Figure 4). For the recordings of IEMG and torque during maximal isometric contractions, the maximum amplitude achieved, following the initial two second build-up period, was measured and recorded for all three repetitions.

A pen on the Hewlett Packard recorder registered a mark to indicate one second intervals throughout the testing procedures. These markers were valuable in

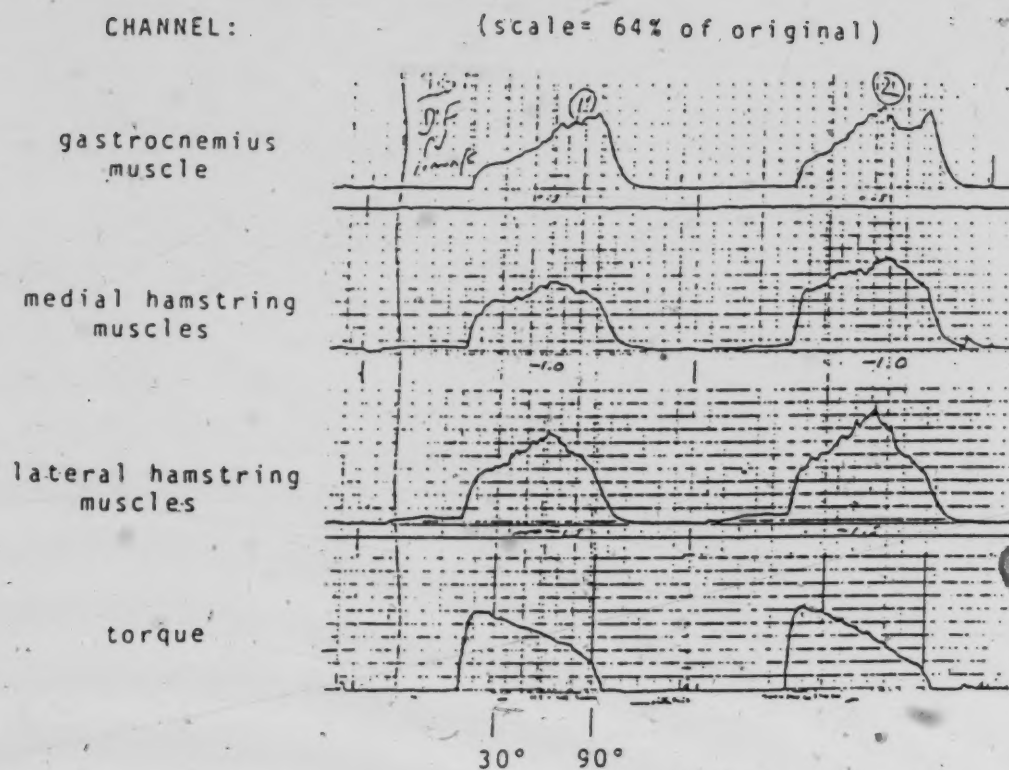


Figure 4: Pen recording of IEMG and torque patterns during an isokinetic test movement. The pen deflections representing 30° and 90° angles of knee flexion are included on the torque channel. The chart speed was 10 mm·s⁻¹

allowing the investigator to determine the end of the isometric build-up segment.

For the isokinetic test repetitions, the IEMG and torque amplitudes recorded at the 10°, 30°, 60°, and 90° angles of knee flexion were measured for all contractions. For isometric and isokinetic test recordings, the mean amplitude of the two efforts closest in amplitude, was calculated. On occasions when the three amplitudes were equidistant, the lowest two amplitudes were averaged, and the highest amplitude was discarded. No standard and universally accepted method of selecting the most representative reading for IEMG or torque was found in the literature, and thus the present format was arbitrary. The mean isometric value calculated for IEMG and torque channels was assigned a value of 100% for purposes of analysis. The isokinetic mean values were expressed as proportions of the 100% reference value established for the particular channel involved. In situations where the mean isokinetic amplitude exceeded that of its isometric reference activity, the isokinetic value was greater than 100%. The percentage values, means, and standard deviations for each individual are displayed in Appendix 4.

Intra-rater reliability in the form of a Pearson product moment correlation was found to be very high ($r_r = 0.99$), and is displayed in Appendix 3.

Tibial position (three levels) and angle of knee flexion (four levels) were designated as the independent variables for the statistical analysis. A two-way analysis of variance (ANOVA) with repeated measures on both factors was performed for each IEMG channel and the torque channel. The dependent variables were %IEMG and %torque. The analysis is graphed in Table 1. Tukey procedures were done as post-hoc analyses for statistically significant main effects in order to locate statistically significant pairwise contrasts. The level of statistical significance set for the ANOVA and Tukey procedures was $P < .05$.

Table 1. Data analyses format. The two-way ANOVA with repeated measures on both factors

Tibial Position	Knee Angle			
	10°	30°	60°	90°
(1) normal	%IEMG*			
(2) external				
(3) internal				

*Dependent Variable. The dependent variable for torque was
%torque

CHAPTER FOUR

RESULTS

The findings of the present study were categorized for purposes of presentation according to the research hypotheses stated in Chapter One. Subject characteristics are presented in Table 2 and a sample tracing of raw data is shown in Figure 4. Table 3 includes mean scores and standard deviations for all angles at each tibial position for the dependent variables. These scores are depicted graphically in Figures 5 to 8.

Hypothesis One

The first research hypothesis stated that the mean %IEMG would significantly differ among the four knee flexion angles analyzed for the following muscles: (a) lateral hamstrings, (b) medial hamstrings, and (c) gastrocnemius. Hypothesis one can be conveniently subdivided into 1a, 1b, and 1c with reference to the lateral hamstring muscle, medial hamstring muscle, and gastrocnemius muscle, respectively.

1a. The mean %IEMG scores for the lateral hamstrings at each angle are found in Table 4. A two-way ANOVA

Table 2. Age and sex characteristics for subjects

Number of subjects: female = 19

Mean age (years): 26.3

(S.D.): (3.7)

Age range (years): 21-35

Table 3. Mean values of %integrated electromyography and %torque scores

Dependence Variable	Tibial Position	ANGLE OF KNEE FLEXION*			
		10°	30°	60°	90°
Channel 1: %IEMG	Normal	29.3 [†]	98.2	131.7	175.4
	Rotation (NR)	(27.5) [†]	(42.7)	(68.5)	(91.4)
	External	29.6	84.5	121.8	158.4
Gastrocnemius Muscle	Rotation (ER)	(26.9)	(33.4)	(51.4)	(85.2)
	Internal	22.5	77.5	125.4	180.8
	Rotation (IR)	(15.2)	(27.9)	(61.7)	(109.2)
Channel 2: %IEMG	NR	29.3	88.6	115.9	106.4
		(21.5)	(23.4)	(61.5)	(83.9)
	ER	30.6	104.7	135.7	110.7
Lateral Hamstrings		(27.9)	(36.2)	(91.4)	(93.0)
	IR	21.8	68.3	97.4	95.6
		(24.0)	(23.3)	(36.1)	(71.8)
Channel 3: %IEMG	NR	28.2	96.7	109.5	97.4
		(29.4)	(21.5)	(37.2)	(46.1)
	ER	23.4	83.5	98.6	87.3
Medial Hamstrings		(23.0)	(21.5)	(38.6)	(55.6)
	IR	27.2	97.7	124.7	105.7
		(30.7)	(24.0)	(45.2)	(50.9)
Channel 4: %Torque	NR	33.8	97.6	76.4	46.1
		(44.2)	(17.2)	(15.4)	(13.5)
	ER	32.3	96.7	75.9	45.9
		(41.0)	(17.7)	(17.8)	(17.9)
	IR	22.2	87.6	73.2	41.2
		(37.4)	(22.5)	(18.1)	(13.4)

* Complete knee extension equals 0°.

[†] The means are expressed as a percentage of their reference activity,
i.e. the reference is equal to 100%.

[†](standard deviation)

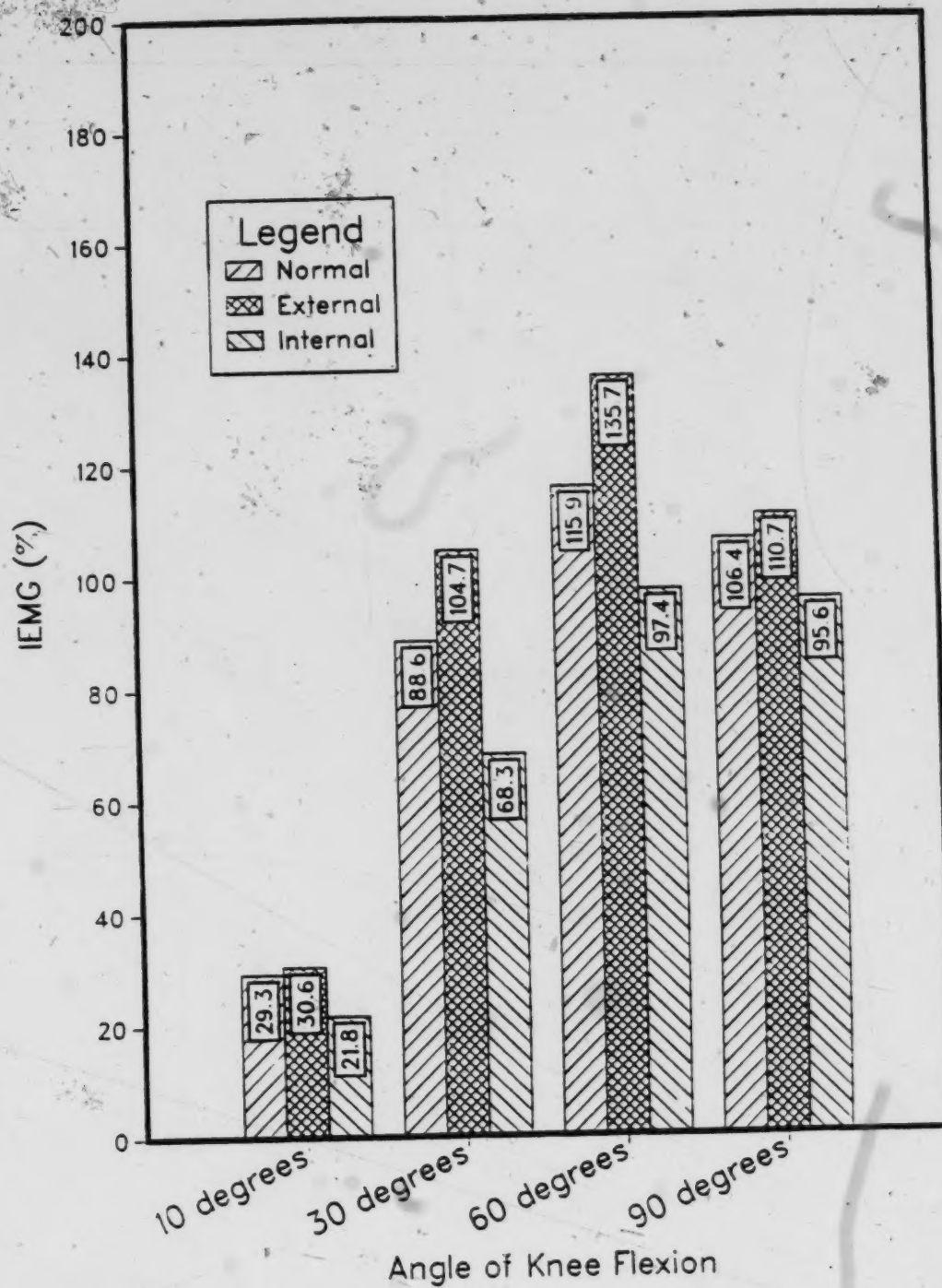


Figure 5. Electromyographic activity of the lateral hamstring muscle group in the three specified tibial positions at the four angles studied

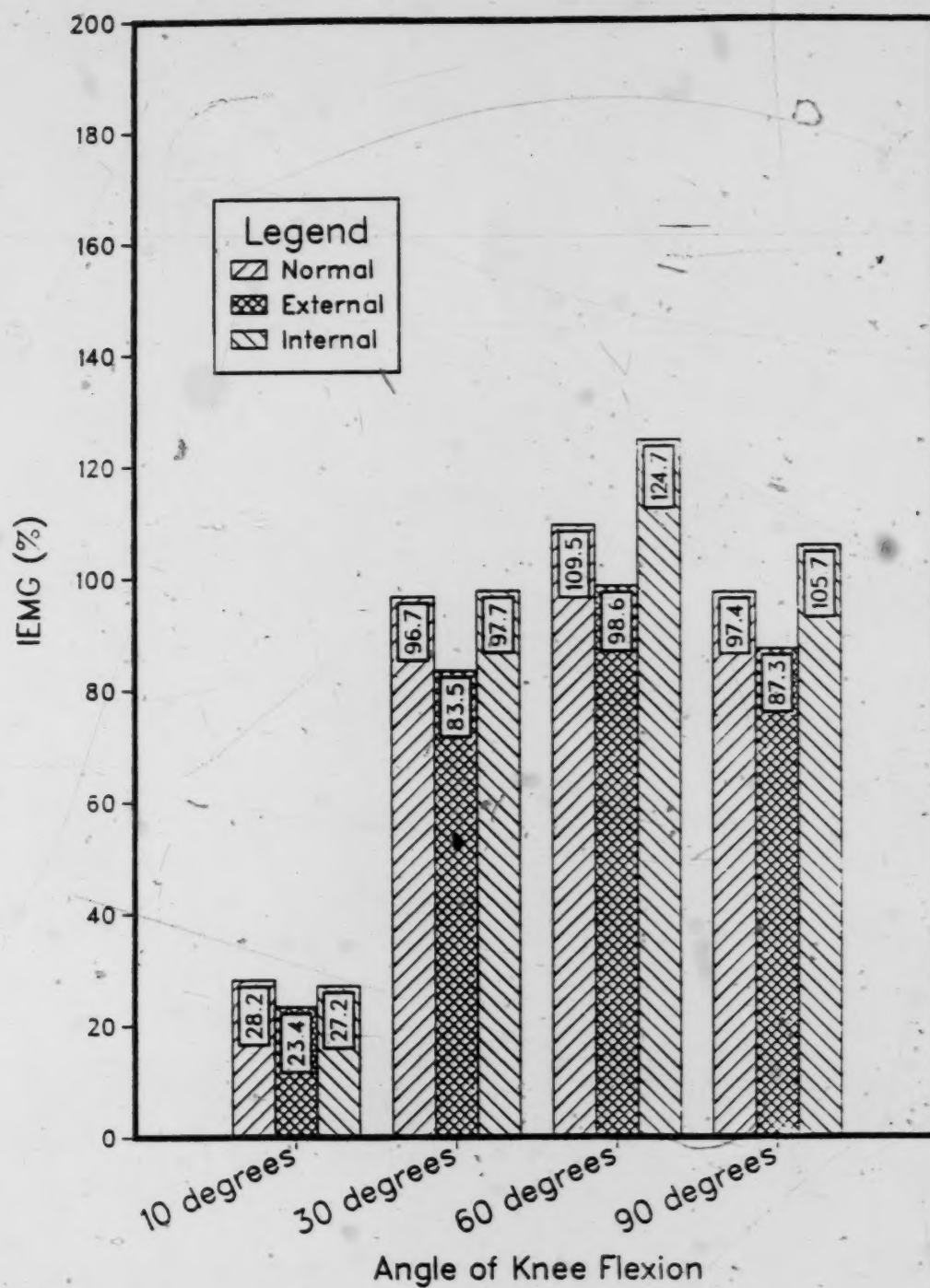


Figure 6. Electromyographic activity of the medial hamstring muscle group in the three specified tibial positions at the four angles studied

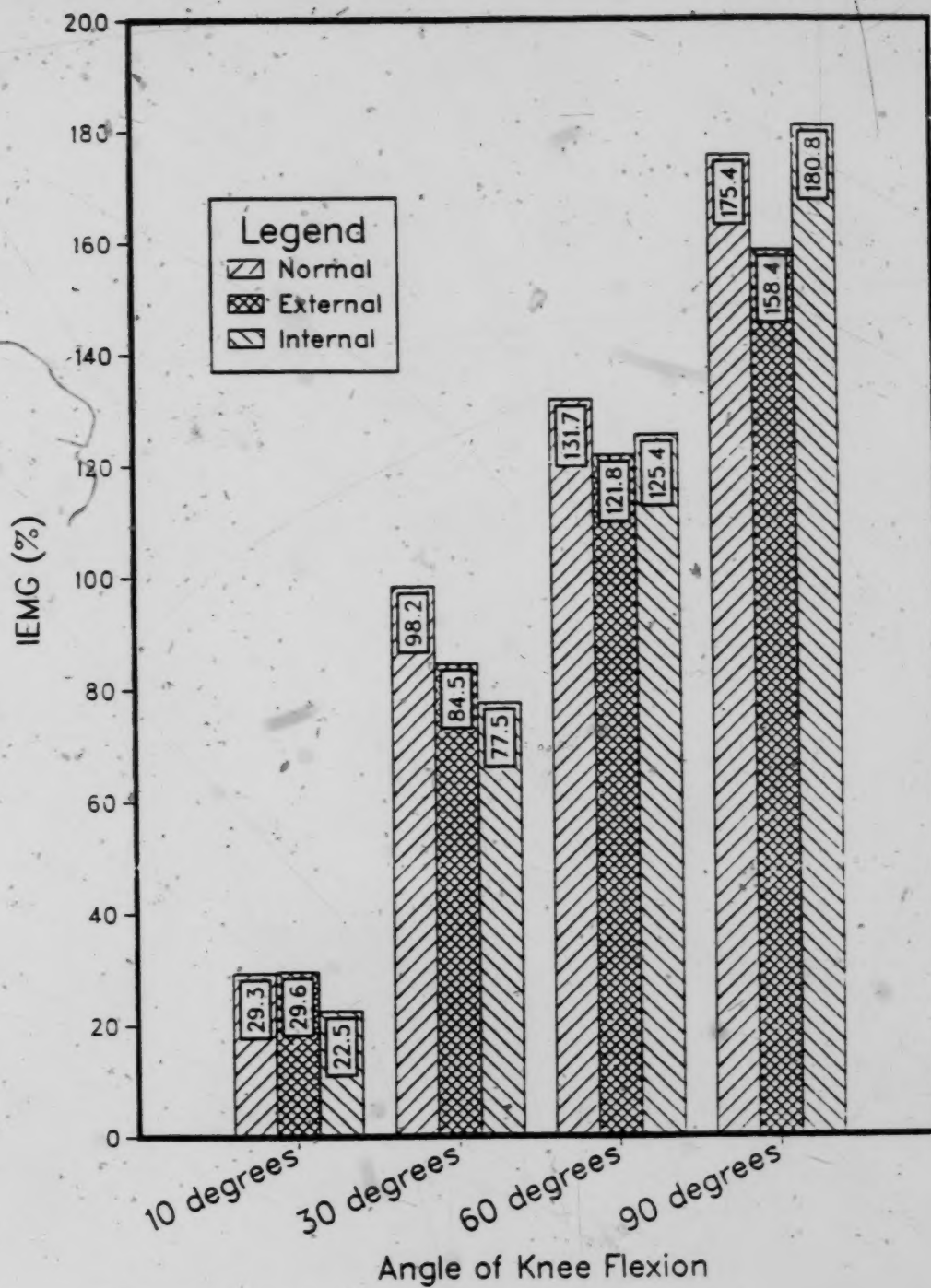


Figure 7. Electromyographic activity of the gastrocnemius muscle in the three specified tibial positions at the four angles studied

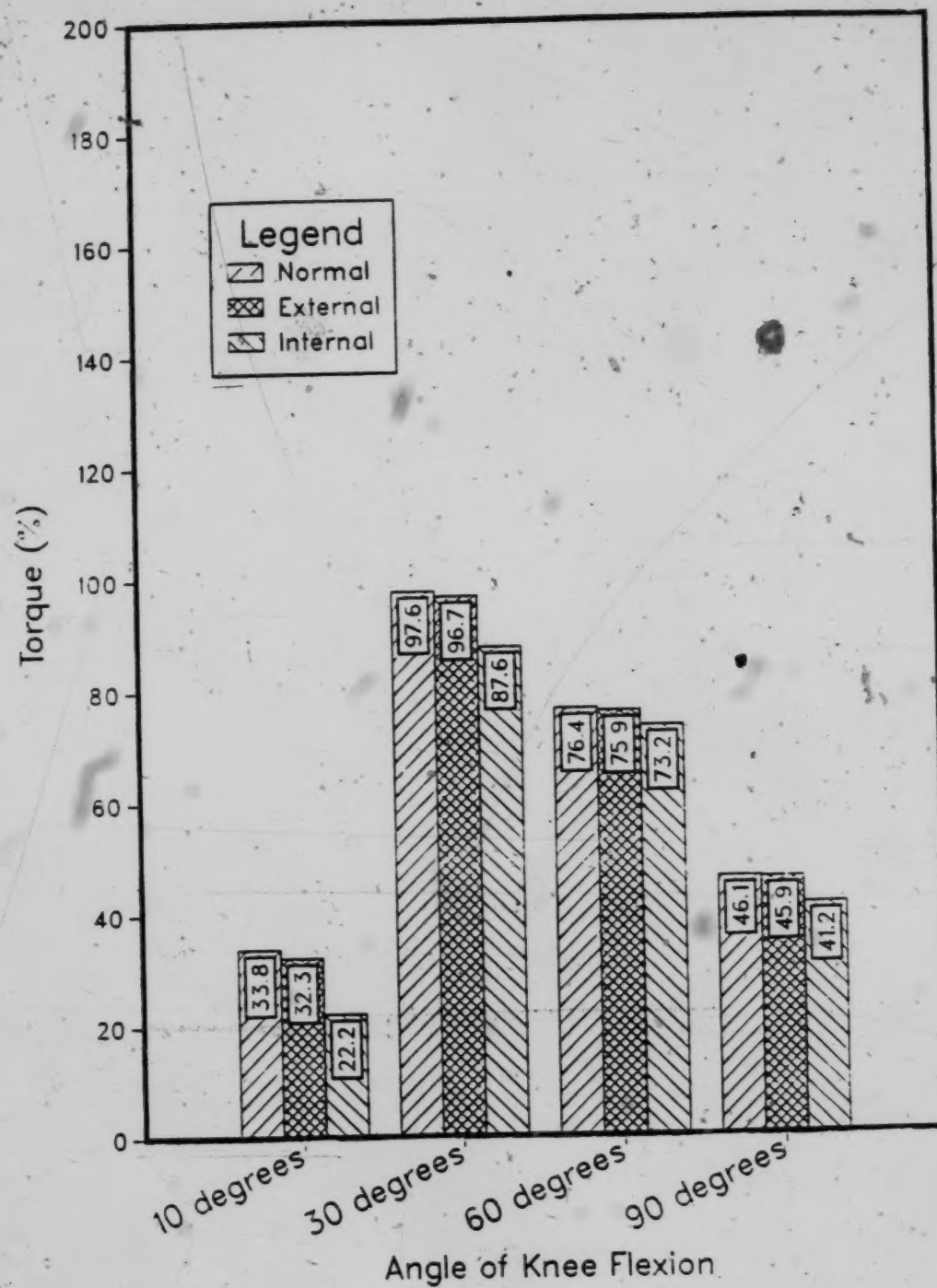


Figure 8. Torque productions of the knee flexor muscles in the three specified tibial positions at the angles studied

Table 4. Main effects for knee angle. Mean %IEMG and %torque comparisons with reference to angle

Dependent Variable	ANGLE			
	10°	30°	60°	90°
(a) %IEMG Lateral Hamstrings	27.2*	87.2	115.4	104.2
(b) %IEMG Medial Hamstrings	26.2	92.6	110.9	96.8
(c) %IEMG Gastrocnemius	27.1	86.7	126.3	171.5
(d) %Torque	29.4	94.0	75.2	44.4

100% = value of the respective reference activity for each dependent variable

*The scores were obtained by averaging the mean% scores for the three tibial positions at each of the four angles

demonstrated significance at the $P < 0.001$ level (Table 5). The significant main effect for angle called for Tukey multiple comparison procedures (Table 6), which determined that the overall significant main effect was due to the difference in the following three pairs of means: (1) 10° versus 30° , (2) 10° versus 60° , and (3) 10° versus 90° . The main effect comparisons are graphed in Figure 9.

1b. The mean % IEMG scores for the medial hamstrings at each angle are displayed in Table 4. A two-way ANOVA showed significance of the $P < 0.001$ level (Table 7). Tukey's procedure (Table 8) showed that the overall significant main effect was due to the difference in the following three pairs of means: (1) 10° versus 30° , (2) 10° versus 60° , and (3) 10° versus 90° . Figure 10 depicts the main effect comparisons.

1c. The mean % IEMG scores for the gastrocnemius muscle at each angle are shown in Table 4. A two-way analysis of variance showed the differences to be significant at the $P < 0.001$ level (Table 9). Because a significant main effect was found for angle, the Tukey multiple comparison procedure was employed. As shown in Table 10, the overall significant main effect was due to the difference in the following four pairs of means: (1) 10° versus 30° , (2) 10° versus 60° , (3) 10° versus 90° ,

Table 5. Analysis of variance summary for the lateral hamstring muscle group

n = 19	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probability
A: Knee Angle	Between Groups	26.379	3	8.793	18.286	0.001*
	Within Groups	25.967	54	0.481		
B: Tibial Position	Between Groups	2.472	2	1.236	10.808	0.001*
	Within Groups	4.117	36	0.114		
AB: Interaction	Between Groups	0.716	6	0.119	3.285	0.005*
	Within Groups	3.923	108	0.036		

* Significant

Table 6. Significant comparisons of the lateral hamstring muscle group between levels of knee angle following Tukey's test on mean scores

Levels of Angle	Means	Probability
10 vs 30	27.2 - 87.2	$P < 0.05^*$
10 vs 60	27.2 - 115.4	$P < 0.05^*$
10 vs 90	27.2 - 104.2	$P < 0.05^*$

* Significant

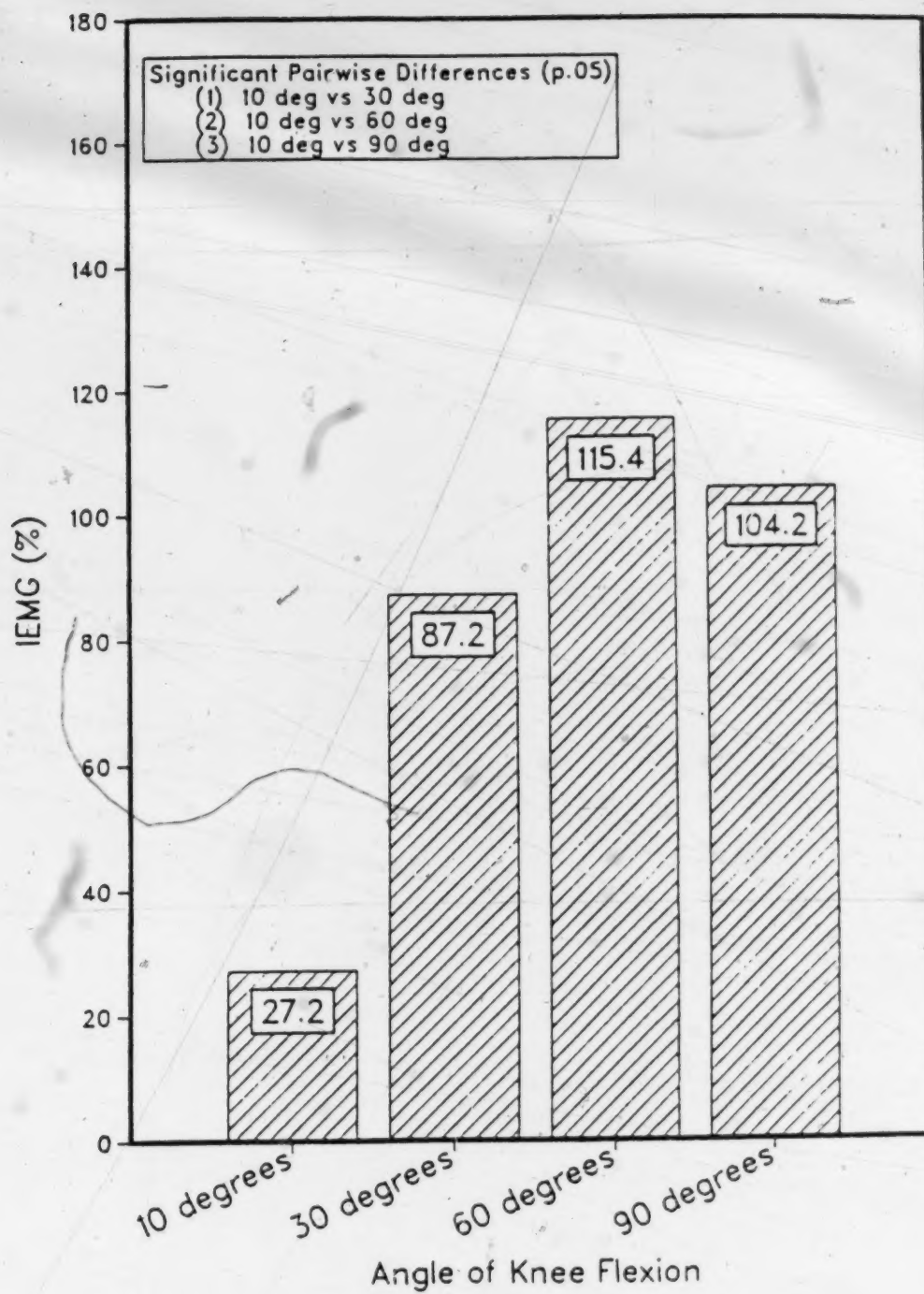


Figure 9. Lateral hamstrings: main effects for angle.

Table 7. Analysis of variance summary for the medial hamstring muscle group

n = 19	Source of Variation	Degrees of Freedom			Mean Squares	F Ratio	Probability
		Sum of Squares	of	Freedom			
A: Knee Angle	Between Groups	24.389	3		8.130	25.876	0.001*
	Within Groups	16.966	54		0.314		
B: Tibial Position	Between Groups	0.949	2		0.474	18.230	0.001*
	Within Groups	0.937	36		0.026		
AB: Interaction	Between Groups	0.294	6		0.049	2.741	0.016*
	Within Groups	1.931	108		0.018		

* Significant

Table 8. Significant comparisons of the medial hamstring muscle group between levels of knee angle following Tukey's test on mean scores

<u>Levels of Angle</u>	<u>Means</u>	<u>Probability</u>
10 vs 30	26.2 - 92.6	$P < 0.05$
10 vs 60	26.2 - 110.9	$P < 0.05$
10 vs 90	26.2 - 96.8	$P < 0.05$

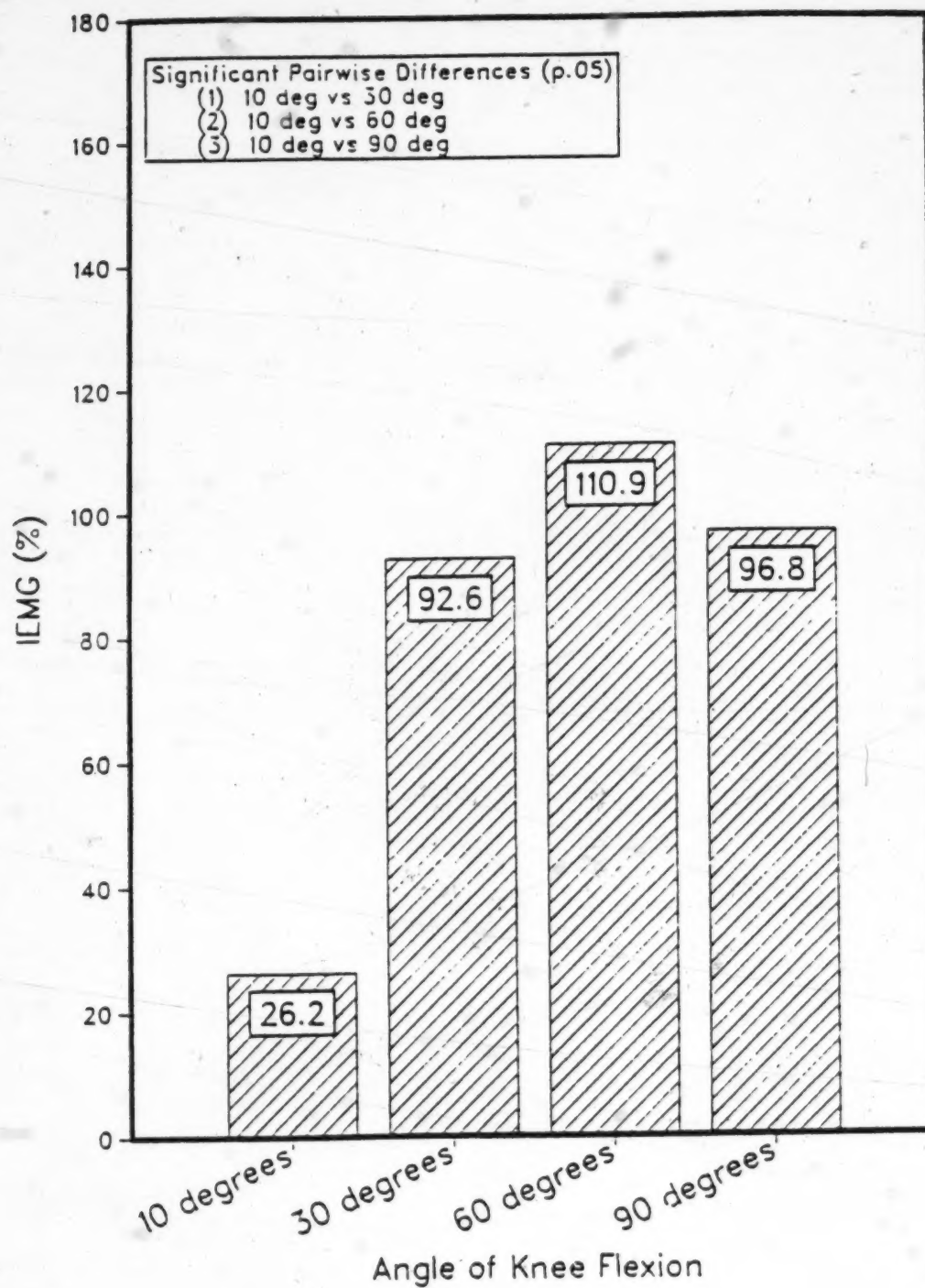


Figure 10. Medial hamstrings: main effects for angle.

Table 9. Analysis of variance summary for the gastrocnemius muscle

n = 19	Source of Variation	Degrees of Freedom			F		Probability
		Sum of Squares	Mean Squares	Ratio	Ratio	Ratio	
A: Knee Angle	Between Groups	64.221	21.407	36.637	0.001*		
	Within Groups	31.552	0.584				
B: Tibial Position	Between Groups	0.407	0.203	1.707	0.196**		
	Within Groups	4.288	0.119				
AB: Interaction	Between Groups	0.693	0.115	2.793	0.014*		
	Within Groups	4.456	0.041				

* Significant

** Nonsignificant

Table 10. Significant comparisons between levels of knee angle following Tukey's test on mean scores (Gastrocnemius Muscle) (refer to Table 3)

<u>Levels of Angle</u>	<u>Means</u>	<u>Probability</u>
10 vs 30	27.1 - 86.7	$P < 0.05$
10 vs 60	27.1 - 126.3	$P < 0.05$
10 vs 90	27.1 - 171.5	$P < 0.05$
30 vs 90	86.7 - 171.5	$P < 0.05$

and (4) 30° versus 90°. These comparisons are graphically displayed in Figure 11. The $P < 0.05$ level of significance was set for all Tukey procedures done.

Hypothesis Two

The second research hypothesis was that the mean %torque would significantly differ among the four angles of knee flexion analyzed. The mean %torque scores are displayed in Table 4. The two-way ANOVA confirmed statistical significance at the $P < 0.001$ level (Table 11). Tukey's procedure (Table 12) demonstrated that the overall significant main effect was due to the difference between the following four pairs of means: (1) 10° versus 30°, (2) 10° versus 60°, (3) 30° versus 90°, and (4) 60° versus 90°. Main effects are shown graphically in Figure 12.

Hypothesis Three

Hypothesis three stated that the mean %IEMG would significantly differ among the three positions of tibial rotation analyzed for the following muscles: (a) lateral hamstrings, (b) medial hamstrings, and (c) gastrocnemius. Hypothesis three can be conveniently subdivided into 3a, 3b, and 3c.

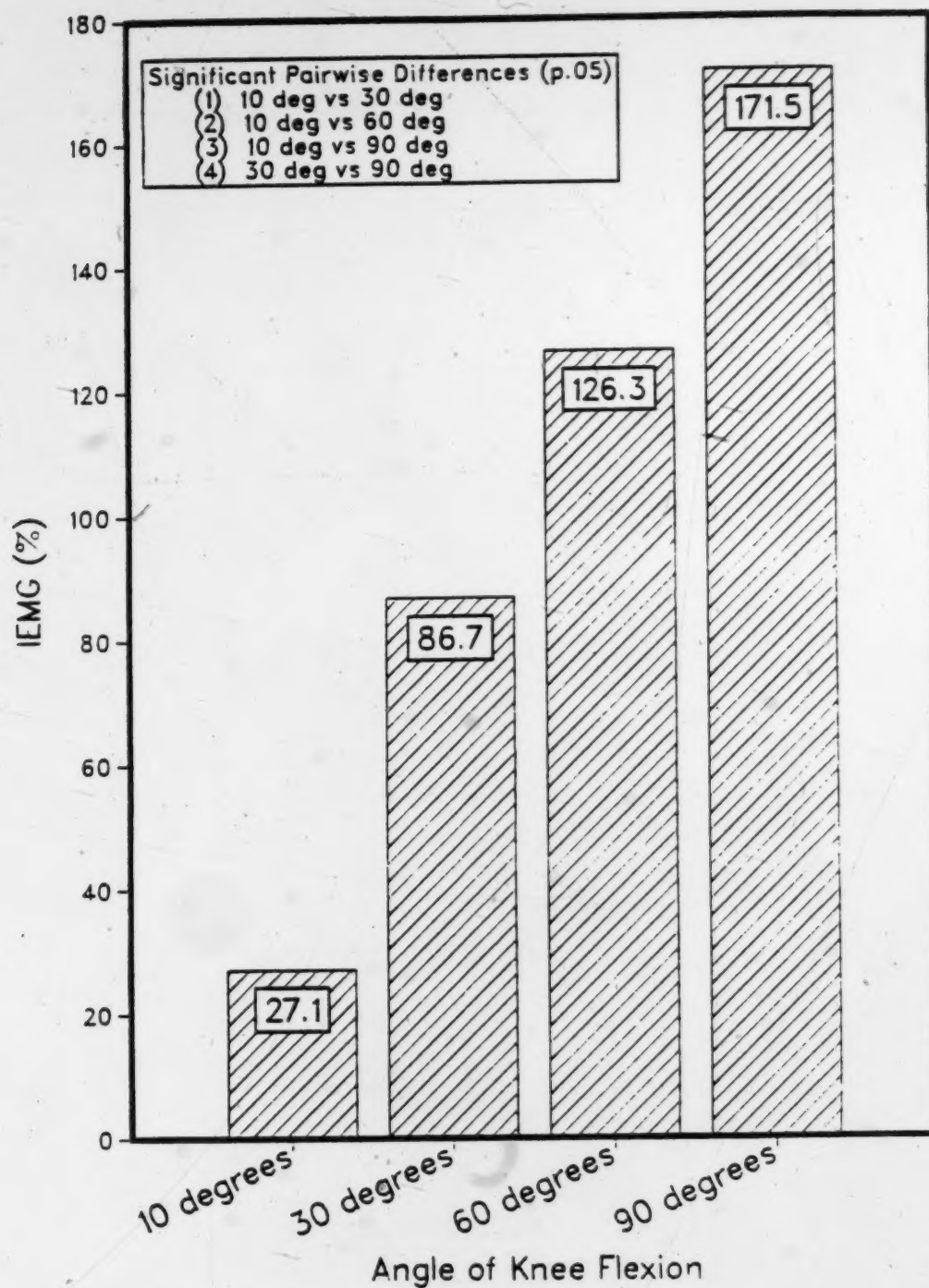


Figure 11. Gastrocnemius: main effects for angle.

Table 11. Analysis of variance summary for the production of torque

n = 19	Source of Variation	Degrees of Freedom		Mean Squares	F Ratio	Probability
		Sum of Squares	of Freedom			
A: Knee Angle	Between Groups	14.586	3	4.862	31.109	0.001*
	Within Groups	8.440	54	0.156		
B: Tibial Position	Between Groups	0.256	2	0.128	8.202	0.001*
	Within Groups	0.561	36	0.016		
AB: Interaction	Between Groups	0.055	6	0.009	1.115	0.358**
	Within Groups	0.889	108			

* Significant

** Nonsignificant

Table 12. Significant comparisons of torque between levels of knee angle following Tukey's test on mean scores

<u>Levels of Angle</u>	<u>Means</u>	<u>Probability</u>
10 vs 30	29.4 - 94.3	$P < 0.05$
10 vs 60	29.4 - 75.2	$P < 0.05$
30 vs 90	94.0 - 44.4	$P < 0.05$
60 vs 90	75.2 - 44.4	$P < 0.05$

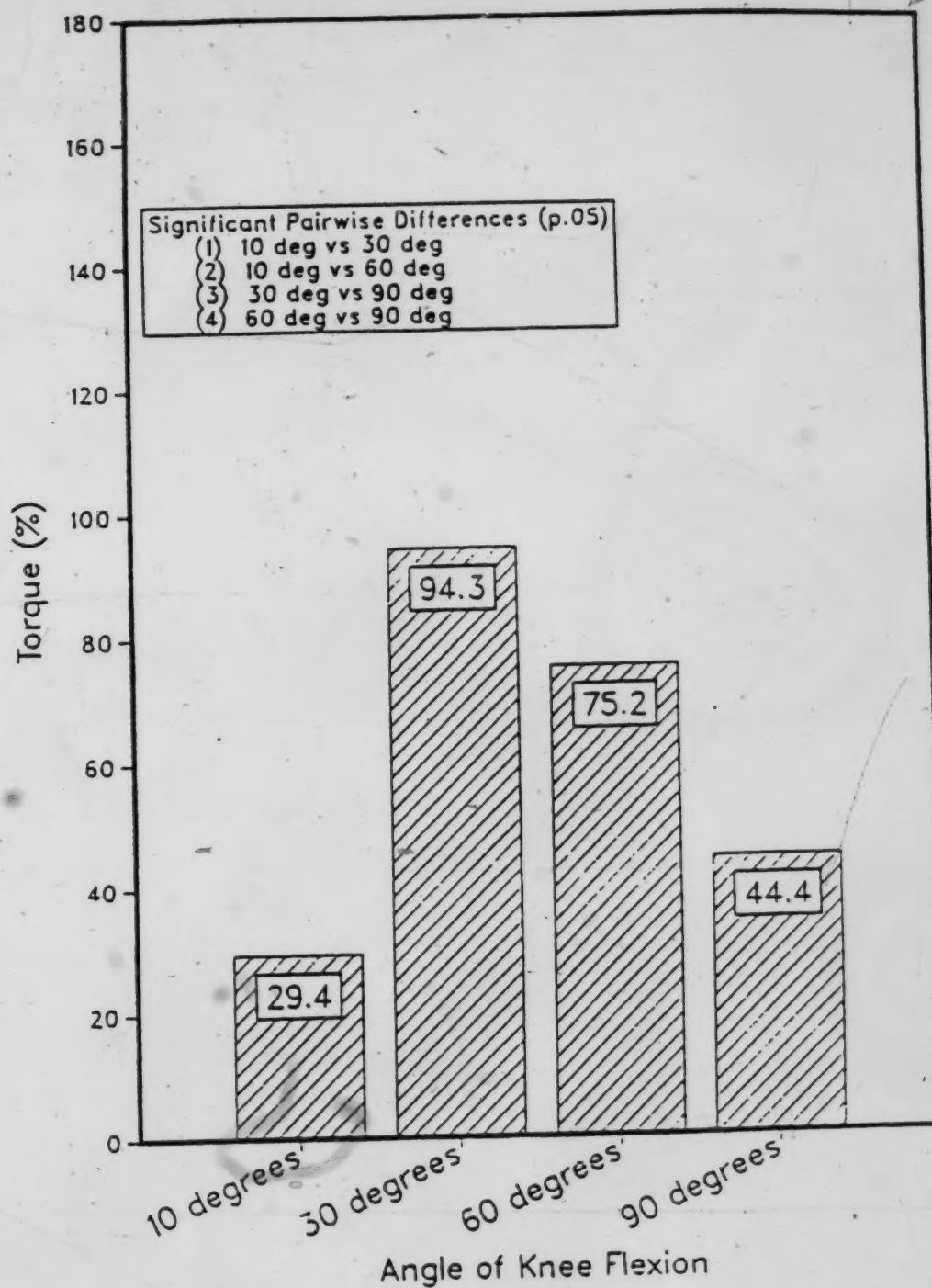


Figure 12. Torque: main effects for angle.

3a. The mean %IEMG scores for the lateral hamstrings at each position are presented in Table 13. A two-way ANOVA showed statistical significance at the $P < 0.001$ level (Table 5). The significant main effect for position necessitated Tukey multiple comparison procedures (Table 14), which determined that the overall significant main effect was due to the difference in the following pair of means: external rotation versus internal rotation ($P < 0.05$). Comparisons for main effects are found in Figure 13.

3b. The mean % IEMG scores for the medial hamstrings at each position are presented in Table 13. A two-way ANOVA showed significance at the $P < 0.001$ level (Table 7). Tukey's procedure (Table 15) demonstrated that the overall significant main effect was due to the difference between the following levels of position: (1) normal rotation versus external rotation, and (2) external rotation versus internal rotation. Refer to Figure 14 for a graphic illustration of main effect comparisons.

3c. The mean %IEMG scores for the gastrocnemius muscle at each position are displayed in Table 13. A two-way ANOVA showed the differences to be nonsignificant (Table 9), obviating the need for post-hoc comparisons. Main effects comparisons are displayed in Figure 15.

Table 13. Main effects for tibial position. Mean %IEMG and %torque comparisons with reference to tibial position

Dependent Variable	Normal Rotation	External Rotation	Internal Rotation
(a) %IEMG Lateral Hamstrings	85.1	95.4	70.1
(b) %IEMG Medial Hamstrings	82.9	73.2	88.8
(c) %IEMG Gastrocnemius	108.6*	98.6	101.5
(d) %Torque	63.5	62.7	56.0

100% = value of the respective activity for each dependent variable

*The scores were obtained by averaging the mean % scores for the four angles at each of the three positions of the tibia

Table 14. Significant comparisons of the lateral hamstring muscle group between levels of tibial position following Tukey's test on mean scores

Levels of Position	Means	Probability
E vs I	95.4 - 70.1	$P < 0.05^*$

*Significant

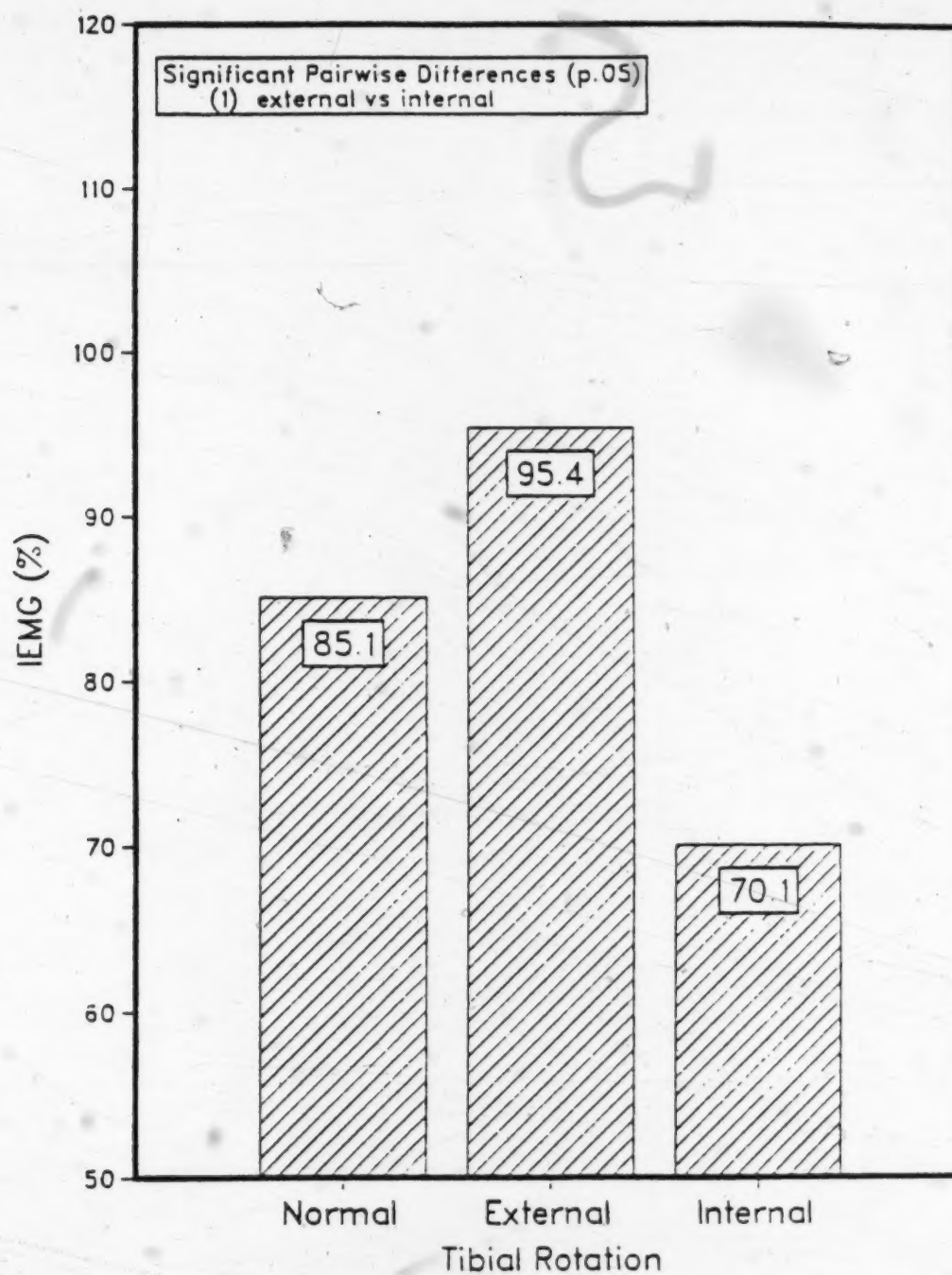


Figure 13. Lateral hamstrings: main effects for position.

Table 15. Significant comparisons of the medial hamstring muscle group between levels of tibial position following Tukey's test on mean scores

<u>Levels of Position</u>	<u>Means</u>	<u>Probability</u>
N vs E	82.9 - 73.2	$P < 0.05$
E vs I	73.2 - 88.8	$P < 0.05$

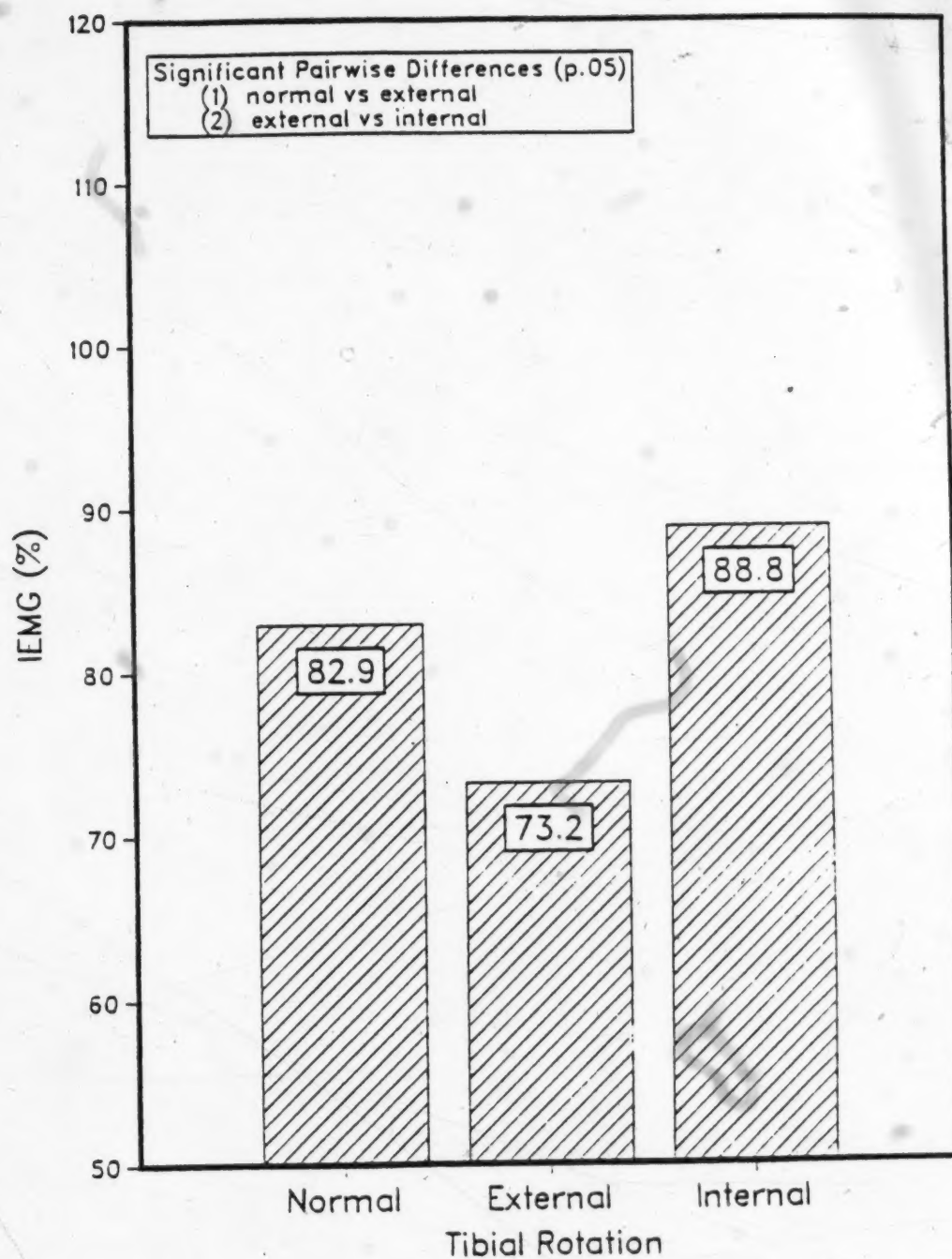


Figure 14. Medial hamstrings: main effects for position.

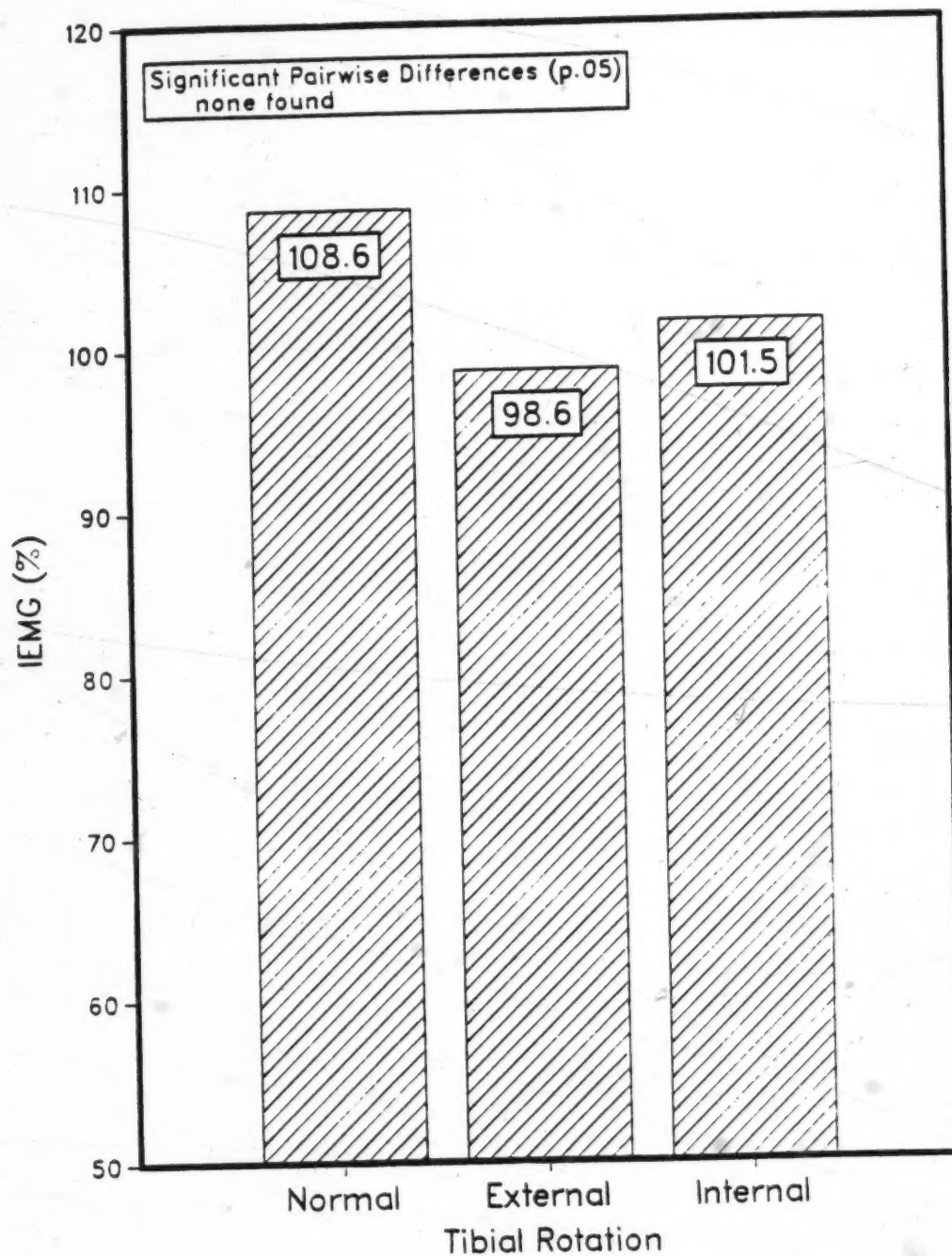


Figure 15. Gastrocnemius: main effects for position.

Hypothesis Four

Research hypothesis four was that the mean torque would differ significantly among the three positions of tibial rotation. The mean torque scores are presented in Table 13. A two-way ANOVA confirmed statistical significance at the $P < 0.001$ (Table 11). Tukey's multiple comparison procedure (Table 16) showed that the overall significant main effect for position was due to the mean difference between the following levels of position:

- (1) normal rotation versus internal rotation, and
- (2) external rotation versus internal rotation. The main effects for position are compared in Figure 16.

Interaction

Overall interaction was found to be statistically significant for the gastrocnemius muscle, the lateral hamstring, and the medial hamstring muscles. Interaction can be graphically illustrated by plotting the levels of one independent variable in relation to the other independent variable (abscissa), and to the dependent variable (ordinate). Departure from parallelism of the plotted lines indicates that an interaction effect exists.

The interaction effects for the lateral hamstring muscles, medial hamstring muscles, and the gastrocnemius muscle are shown in Figures 17, 18, and 19, respectively.

Table 16. Significant comparisons of torque between levels of tibial position following Tukey's test on mean scores

<u>Levels of Position</u>	<u>Means</u>	<u>Probability</u>
N vs I	63.5 - 56.0	P < 0.05
E vs I	62.7 - 56.0	P < 0.05

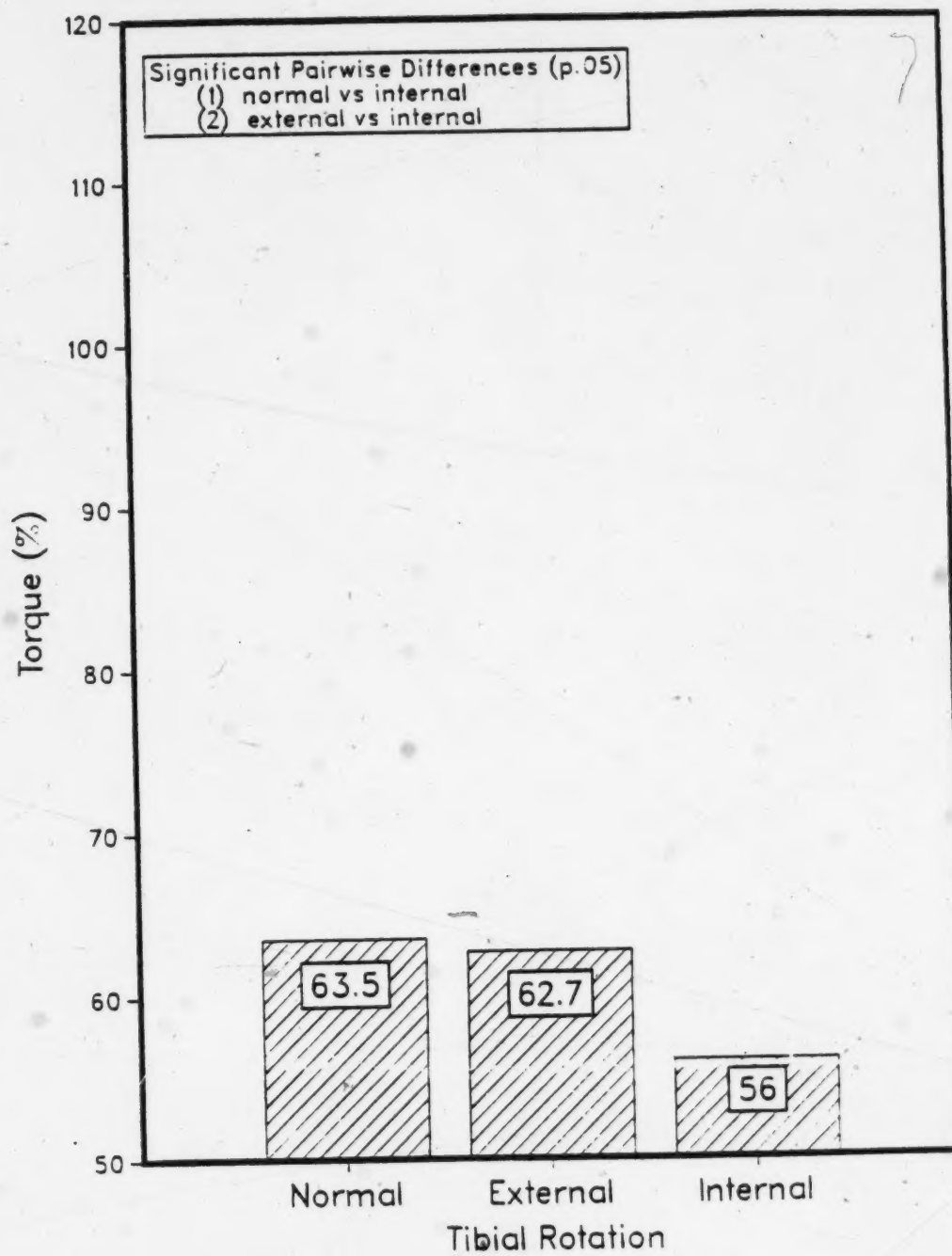


Figure 16. Torque: main effects for position.

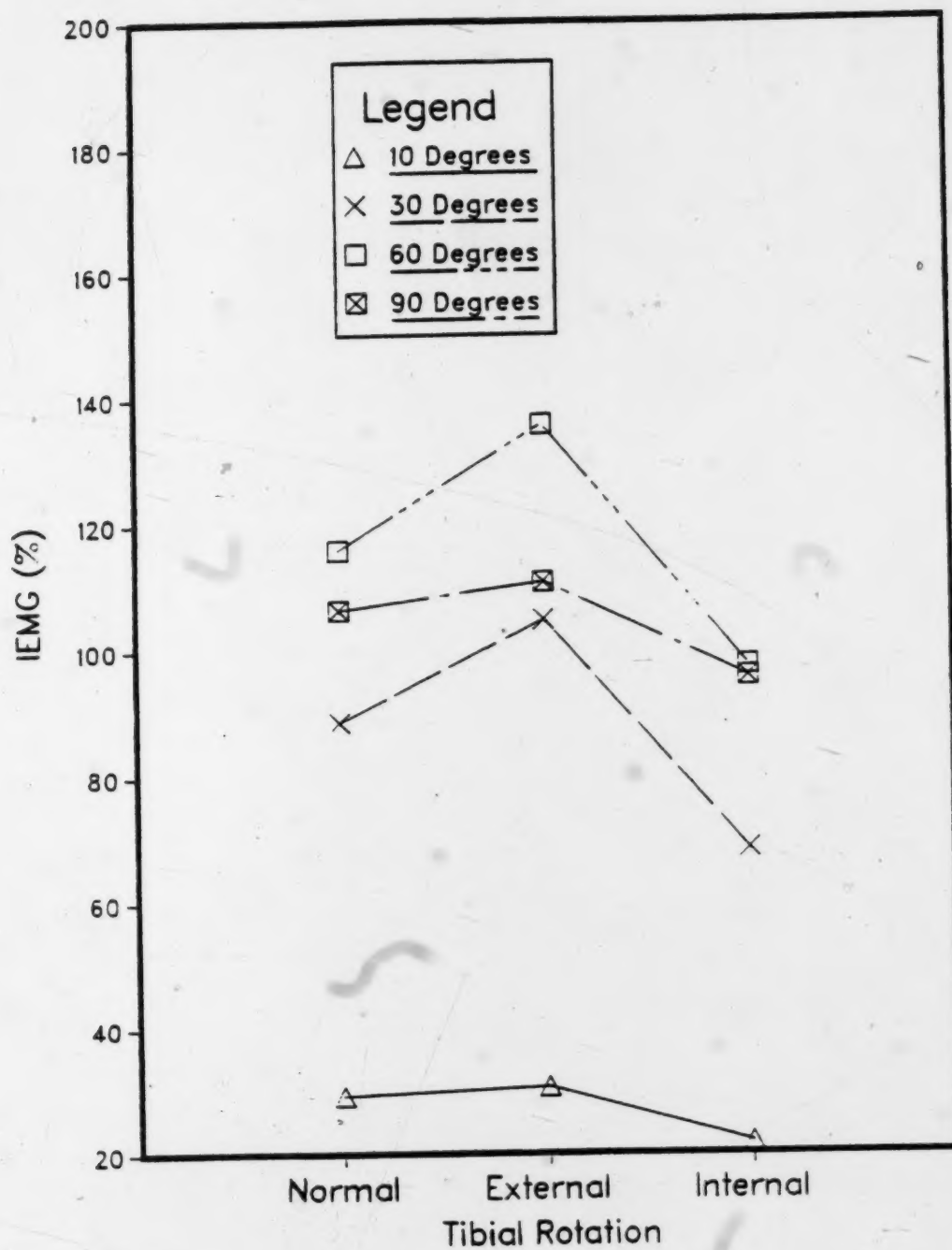


Figure 17. Lateral hamstrings: interaction effects

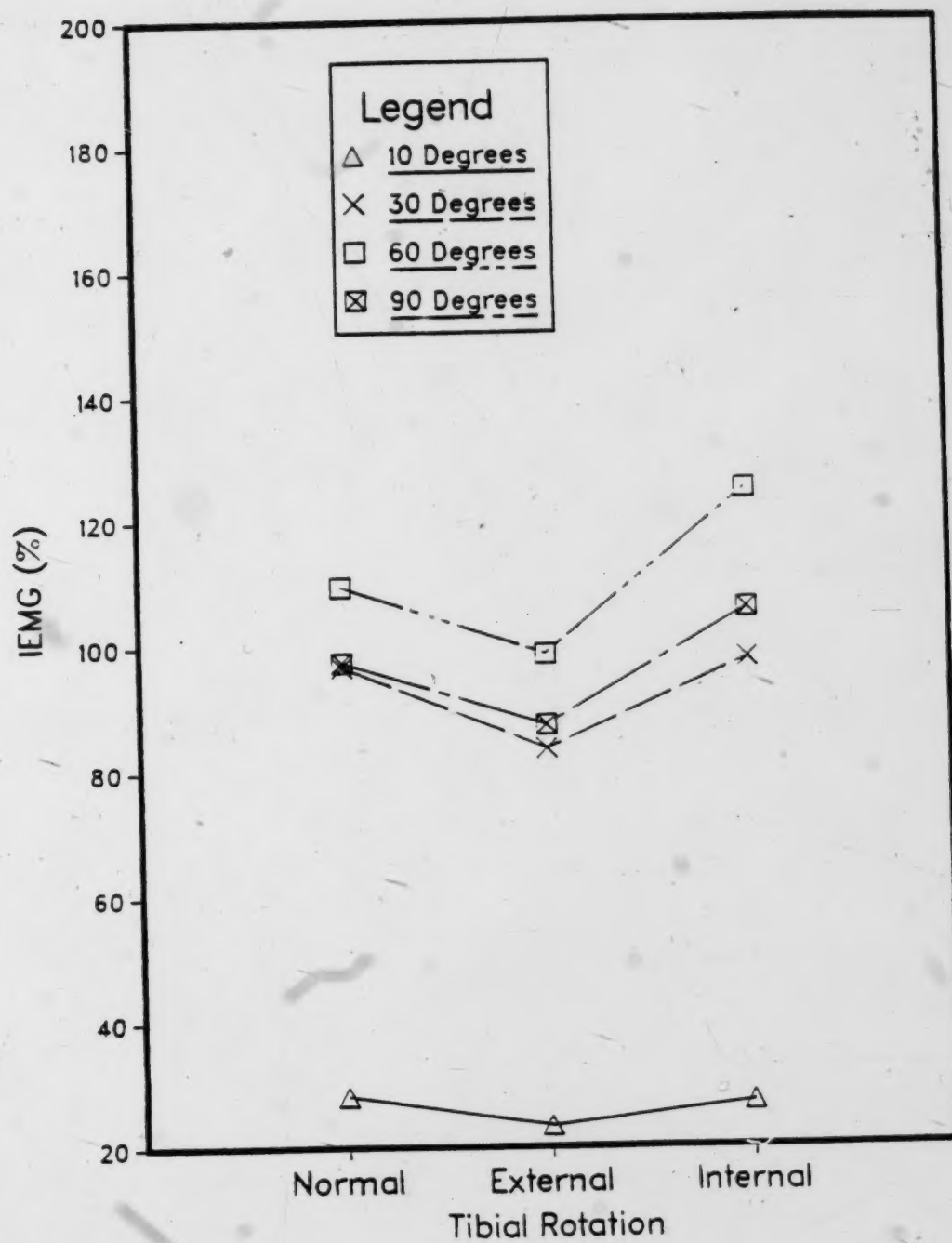


Figure 18. Medial hamstrings: interaction effects

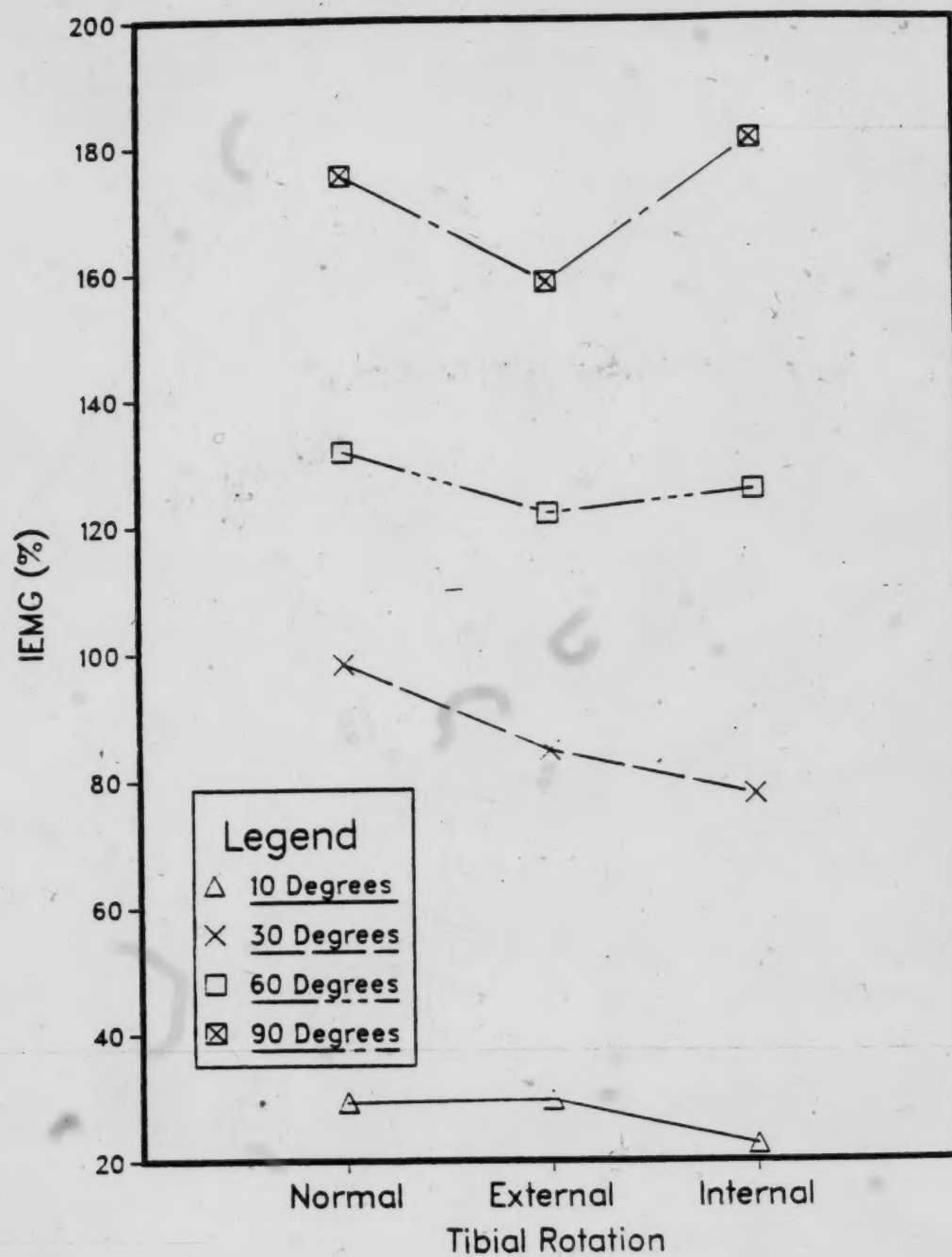


Figure 19. Gastrocnemius: interaction effects.

All subjects were able to complete the practice session and test procedures. No ill effects were reported during or following the testing procedures, other than mild muscular soreness. Initially, the sample size was set at 20. However, subject number 1 was removed from the data analysis because of missing data for all channels at the 90° knee flexion angle. The sample size was too small to warrant the calculation of a linear regression analysis for the missing data.

CHAPTER FIVE

DISCUSSION

The purpose of the present study was twofold. First, to examine IEMG activity for the three muscle groups examined, i.e. lateral hamstrings, medial hamstrings, and gastrocnemius, during slow isokinetically-resisted knee flexion, in combination with normal rotation, external rotation, and internal rotation of the tibia on the stabilized femur. Second, to examine the torque produced during the defined test movements. IEMG and torque values were expressed as percentages of their respective reference activities. The four angles of knee flexion chosen for quantitative analysis were 10°, 30°, 60°, and 90°. The angular velocity selected was 18°/s.

The results of the present investigation will be discussed initially within the framework of the four hypotheses as stated in Chapter One.

Hypothesis One

1a. Visual inspection of the main effects for angle on the lateral hamstring muscle group (Figure 9) shows a progressive rise in %IEMG until the 60° angle of knee

flexion, beyond which it declines slightly. The main effect for angle was statistically significant and the post-hoc Tukey procedure found the significant differences to lie between 10° versus 30° , 10° versus 60° , and 10° versus 90° . Other pair-wise comparisons were not statistically significant. However, the percentage increase between 30° and 60° was 28.2% and did approach significance.

1b. The histogram depicting medial hamstring activity related to knee angle (Figure 10) displays a close similarity to the general pattern established for the lateral hamstrings. The significant main effects for angle on %IEMG were submitted for Tukey's post-hoc comparison procedure which determined statistical significance between 10° and 30° , 10° and 60° , 10° and 90° . Comparisons between 30° , 60° , and 90° did not achieve or approach significance.

The information derived from the present study concerning the electrical activity of the hamstring muscles invites several important considerations. Firstly, there have been no previously published reports concerning quantitative measurement of the IEMG of these muscles in relation to knee angle during maximally-resisted isokinetic knee flexion. Therefore, the present findings are offered as norms for the population sampled,

i.e. non-athletic females in the age range of 21 to 35 years. Secondly, previous data⁹⁰ collected during maximal isometric efforts of the quadriceps muscles showed that female subjects achieved peak IEMG activity at a greater angle of knee flexion than did male participants. A future study employing males in the context of the present experimental design would be of value in determining any sex-related differences for the hamstring group.

Assessment of electromyographic data is complicated due to problems of controlling the type and velocity of contraction as well as by the length of the muscles investigated and the joint angles involved.^{40,59} The relevance of these complications is increased when muscles acting over two joints are being recorded.⁷¹ Lunnen et al⁵⁷ established that the effect of changing the length of the biceps femoris, long head, in the absence of an alteration in knee angle, was to cause a decrease in IEMG, at a constant force, when the muscle was in a lengthened position, and to cause an increase in IEMG activity when the muscle was shortened. In the present study, change in muscle length was accompanied by changing muscle force leverages of unknown magnitudes. The IEMG activity of the lateral and medial hamstrings similarly increased between 10° and 30° of knee flexion. Beyond the 30° angle, no statistically significant change occurred in IEMG levels.

related to angle. Therefore, it would appear that the established IEMG-muscle length relationship, as earlier described, was not the only unmeasured relationship affecting the results. Otherwise, one would have expected increases in IEMG between 30°, 60° and 90°. The other major variable of probable influence was that of muscle leverages.

Studies which have considered the effect of muscle lever alterations during maximal efforts have involved the quadriceps femoris muscle group.^{59,71,73,74,121}

Eloranta and Komi⁷¹ studied the surface IEMG patterns of the quadriceps muscles during maximal voluntary efforts into constant velocity knee extension. Strain gauges were situated to enable the investigators to simultaneously record forces generated during the movement. The hip angle was stabilized. Although no statistical analyses were undertaken, the authors showed that peak IEMG was evident in mid-range of knee extension for each member of the quadriceps studied, with declining IEMG in larger ranges of knee flexion and, more dramatic decline towards full knee extension. The writers reasoned that the position of the knee angle, apart from the concomitant muscle length had an influence on the maximum IEMG activity of the quadriceps muscles. Two observations formed the basis of their conclusion. Firstly, in their

opinion, the change in muscle length during the test movement of the biarticular muscle, i.e. the rectus femoris, was less than that of the monoarticular muscles investigated. Nonetheless, the IEMG patterns were not apparently affected by this muscle length change disparity. Secondly, the drop in maximum IEMG as the quadriceps mechanism shortened, i.e. into full knee extension, did not concur with the established IEMG-muscle length relationships which would see a rise in IEMG during muscle shortening. The authors suggested that the maximal nervous input to the quadriceps muscles was in some manner connected to the mechanical leverage of the joint.⁷¹

Moritz and associates^{59,121} conducted an experiment to compare the influences of motor unit activity, length-tension relationship and muscle force leverage on muscle torque. Maximal voluntary isometric efforts into knee extension were elicited at various knee angles. These investigators found in normal subjects, that whereas the torque values peaked at 50° of knee flexion and declined towards further flexion and towards extension, the maximum IEMG values of the quadriceps showed a continual increase from the isometric knee extension position towards the greater angles of knee flexion. The greatest angle studied was 90°. The lack of parallelism between the IEMG and tension with respect to knee angle was conjectured to

be ascribable to a non-linear relationship between averaged EMG and muscle tension. The authors, as a second experiment, had the subjects maintain a constant level of IEMG during isometric efforts at each prescribed angle and determined that the resultant torque pattern closely approximated that obtained during maximal voluntary efforts. In conclusion, it was stated that because the electrical activity was constant at all angles, the changes of muscle lever length were accountable in part for the shape of the torque curve.^{59,121} Lindahl and Movin¹¹⁶ had previously determined that changes in muscle force lever length were responsible for a maximum of 25% reduction in torque in the nearly extended position of the knee, and for a 10% reduction at the 90° angle. Because Moritz et al^{59,121} had observed a 50% decrease in torque at 10° (compared to peak torque at 50°) and a 40% decline at 90°, the variable of muscle length change was regarded as being of equal importance in affecting torque production.

It is important to note that other similar studies of the knee extensor muscles^{73,122} have yielded somewhat different IEMG-torque patterns, suggesting that differences in technique may be partly responsible. Further investigations with consistent test conditions are therefore required.

In summary, the results of the present study have not been in concert with previous experiments when the IEMG-length relationship is considered in isolation. It is apparent from the discrepancies observed that the remaining major identifiable variable, i.e. muscle force lever, must play a significant part in affecting the IEMG pattern of the hamstring muscles during isokinetically resisted knee flexion. The variables affecting IEMG during the earliest portion of the test movement are considered presently with reference to hypothesis 1c (vide infra), and also apply to the hamstring muscle groups. Due to the complexity of factors which operated in the present study, the precise relationship between IEMG and tension was unclear. The contributions of muscle force lever and muscle length change were indeterminate.

1c. The main effects for knee angle on the %IEMG of the gastrocnemius are graphed in Figure 11 of the results section. A progressive increase in %IEMG was found to accompany the increases in knee flexion angle. Tukey's procedure detected that the overall statistically significant main effect could be attributed to significant differences between the %IEMG values at 10° versus 30°, 10° versus 60°, 10° versus 90°, and 30° versus 90° of knee flexion. The comparison between 60° and 90° approached but did not achieve statistical significance. The total

increase in activity was 144.4%, with the largest increment found to be 59.6%, between the 10° and 30° angles.

The rise in IEMG activity in conjunction with increased angles of knee flexion agrees, indirectly, with previous studies of this muscle.^{54,125} Direct comparisons are inappropriate, however, because of the fact that, in contrast to the present study, earlier investigations which dealt with IEMG muscle length relationships in the gastrocnemius muscle achieved alterations in muscle length by altering the degree of dorsiflexion and plantar flexion of the ankle.

Herman and Bragin¹²⁴ studied the electrical activity of the gastrocnemius muscle in various angles of dorsiflexion and plantar flexion of the ankle. During maximal isometric efforts into plantar flexion, IEMG activity was least when the ankle was positioned in maximal dorsiflexion and greatest when the ankle was positioned at 20° of plantar flexion. Between 20° and 30° of plantar flexion, the IEMG dropped sharply. Liberson et al⁵⁴ found the amplitude of IEMG to increase as the muscle assumed progressively shorter lengths, i.e. with increased plantar flexion. Because this finding did not agree with results from experiments on other muscles by the same authors, the writers conjectured that marked

changes in the contours of this muscle observed during resisted plantar flexion probably affected the quantity of IEMG recorded. They reasoned that because the muscle acquired a globe-like contour during resisted contraction, compared to its spindle-like shape at rest, the greater muscle mass projected over the surface recording electrodes might be responsible for an apparent, rather than true, increase of electrical activity. This conjecture was echoed by Soderberg.⁷⁰

The findings of the present study agreed with those of the previous authors^{54,124} for the gastrocnemius muscle and with authors who investigated length-IEMG relationships of other muscles reviewed earlier.^{34,53,56,57} The report by Libet and associates⁵⁶ involving the gastrocnemius muscle agreed with the assertion that IEMG is decreased when extended beyond an intermediate length but in contrast to most studies saw a decrease in IEMG with progressive shortening of the muscle beyond an intermediate length.

In the present experiment, contraction of the gastrocnemius muscle was in association with resisted knee flexion, while the ankle was actively maintained in dorsiflexion. The change in muscle contour appeared to be less than that associated with strongly resisted plantar flexion. The fact that increased electrical activity was

observed with increases in knee angle, is therefore less attributable to artifact, and consequently does not support the artifact hypothesis of Liberson et al.⁵⁴

Several considerations have been brought forth in the literature to account for the decline in electrical activity associated with extreme lengthened positions of a muscle. In terms of the present experiment, the gastrocnemius muscle was almost fully stretched in the starting positions employed for the isokinetic contractions. Grieve and associates,¹²⁷ who employed cadaver specimens to determine length changes in the gastrocnemius muscle, concomitant with angular displacements at the knee and ankle, reported a 6.40% increase in muscle length between the position of 90° knee flexion combined with 90° ankle flexion (dorsiflexion) and the position of 0° knee flexion (knee extension) and 90° ankle flexion. These positions corresponded to those adopted at the extremes of ranges for the present study.

Libet et al.⁵⁶ compared the IEMG activity of the tibialis anterior muscle in its most lengthened position before and following procaine injection to the area of the tendon afferent fibres, i.e. the Golgi tendon organs. Greater IEMG was recorded following local anaesthesia, suggesting that these afferents were responsible for the decreased IEMG activity at extreme lengths of the

muscle. In addition, the decreased contribution of the contractile elements to total tension in lengthened muscle would be manifested by decreased IEMG activity, which is dependent upon developed, i.e. rather than passive, tension for its existence.⁵⁷ This explanation is consistent with the length-tension phenomenon of muscle,⁵⁵ and may be in part due to the number of cross-bridges available between the actin and myosin filaments.²²

Another factor which may have contributed to this phenomenon was the difficulty some subjects demonstrated in maintaining the starting position prior to each isokinetically-resisted effort. Insufficient hamstring flexibility and quadriceps muscle weakness appeared to be the main contributors to the difficulty experienced. To avoid the possibility of interference during the test movements, by the investigator, the subject was instructed to maintain the horizontal starting position of the lower limb very briefly prior to the commencement of each maximal effort. This procedure enabled the investigator to remove his hand, which was supporting the lever arm and the subject's limb. Despite the practice session, the ability to maintain the starting position as requested was not mastered by all subjects. Thus, the commencement of IEMG activity did not occur at a consistent angle of knee flexion for each subject, and all subjects may not have

achieved a maximal effort by the 10° position. This factor may well have contributed to the inter-subject variability for all muscles monitored at the 10° angle. The variability was reflected in a relatively large standard deviation.

The presence of increased IEMG activity in conjunction with muscle shortening, as observed in the present study, was theorized by Heckathorne and Childress⁵³ to be related to two main factors: (1) the decreased mechanical capability of the individual sarcomeres to generate force at shorter lengths, and (2) impairment of the activation-contraction coupling at shortened muscle lengths. A twitch induced by a motor unit action potential is of shorter duration and decays more quickly. Hence, to create a certain force, the activation system must compensate by increasing the amount of motor unit stimulation and consequently, the amount of electromyographic activity.⁵³

A variable which was present throughout the testing in the present study was the ankle position. In an effort to simulate normal clinical conditions, an elaborate stabilization of the ankle was not attempted. The ankle was observed in several subjects to change angle minimally, although no means of accurate determination of angular displacement was in place. In rare instances, due

to observed obvious changes in IEMG traces associated with ankle displacement, the subject was asked to repeat the test movement. Also, the consistent practice of averaging the closest two IEMG recordings and discarding the third, was intended to reduce the chance of including data associated with error due in part to inconsistency in subject performance. For the most part, variation in ankle angle during the test movements was estimated to be less than 5° , and on many occasions, it was negligible. This variable must, however, be considered as a probable contributor to the standard deviation calculated for the gastrocnemius muscle for all angles studied.

Hypothesis Two

The hypothesis of a statistically significant main effect for angle on torque was verified in the present study. Of the four angles examined the greatest torque was found at 30° of knee flexion. Tukey's procedure identified the following significant pairwise comparisons: 10° versus 30° , 10° versus 60° , 30° versus 90° , and 60° versus 90° (Figure 12). The torque at 60° was 19.1% more than that at 30° , but was not statistically significant. A larger sample size would, perhaps, have allowed this comparison to achieve statistical

significance. The present results, therefore are in agreement with those of Moffroid et al,⁸⁶ who, employing female (n=48) and male (n=12) subjects, established norms for isokinetically-resisted maximal knee flexor torque, with the subjects positioned in sitting. The velocity of the movement was 3.75 RPM, slightly faster than that of the present experiment. The exact hip angle was not reported but approximated the vertical, as demonstrated in a photograph. The maximum torque was achieved at the knee angle of 34°, and thus was in general agreement with the present results. An earlier report by Williams and Stutzman⁹¹ was also in agreement, although their data was measured in terms of force rather than torque, and was measured isometrically. Isometric torque curves and slow isokinetic curves have been shown to be very similar pertaining to angle of peak torque.^{88,90} The contribution to torque by the subject's leg and lever arm was not subtracted from the data reported by Moffroid et al⁹⁰ nor from that in the present study, rendering the respective results comparative in this regard. Knowledge of the hip angle employed by the previous investigators⁸⁸ would have allowed a more direct comparison.

Knapik et al⁹⁰ found maximum knee flexor torque to occur at 20° in a female sample, isometrically, and at 36°/s. Houtz and associates,⁹³ conversely found the

majority of female subjects to attain peak knee flexor torque at 60° of flexion when the subjects were seated. Neither study reported the angle of hip flexion used, and the latter study did not include external stabilization procedures. The importance of the knowledge of hip angle was previously discussed (Chapter Two: Isokinetic Exercise), for purposes of inter-study comparability.

The observation that wide individual variability has been found in the location of peak torque for knee flexion was emphasized by Scudder.⁸⁸ A typical torque curve, such as recorded in the present experiment has been presented in Figure 4, and compares closely with regard to general contour to that shown in Figure 2.

Biomechanical Considerations

The influence of joint angle alteration on muscle torque capability can be discussed by employing biomechanical models. A comparison can then be made to the in vivo situation in order to clarify the roles of muscle force lever and length-tension characteristics of muscle in a basic theoretical framework.

Referring to Figure 20, a model is presented to demonstrate the turning effect of the hamstring muscles under the following major assumptions: (1) the axis of

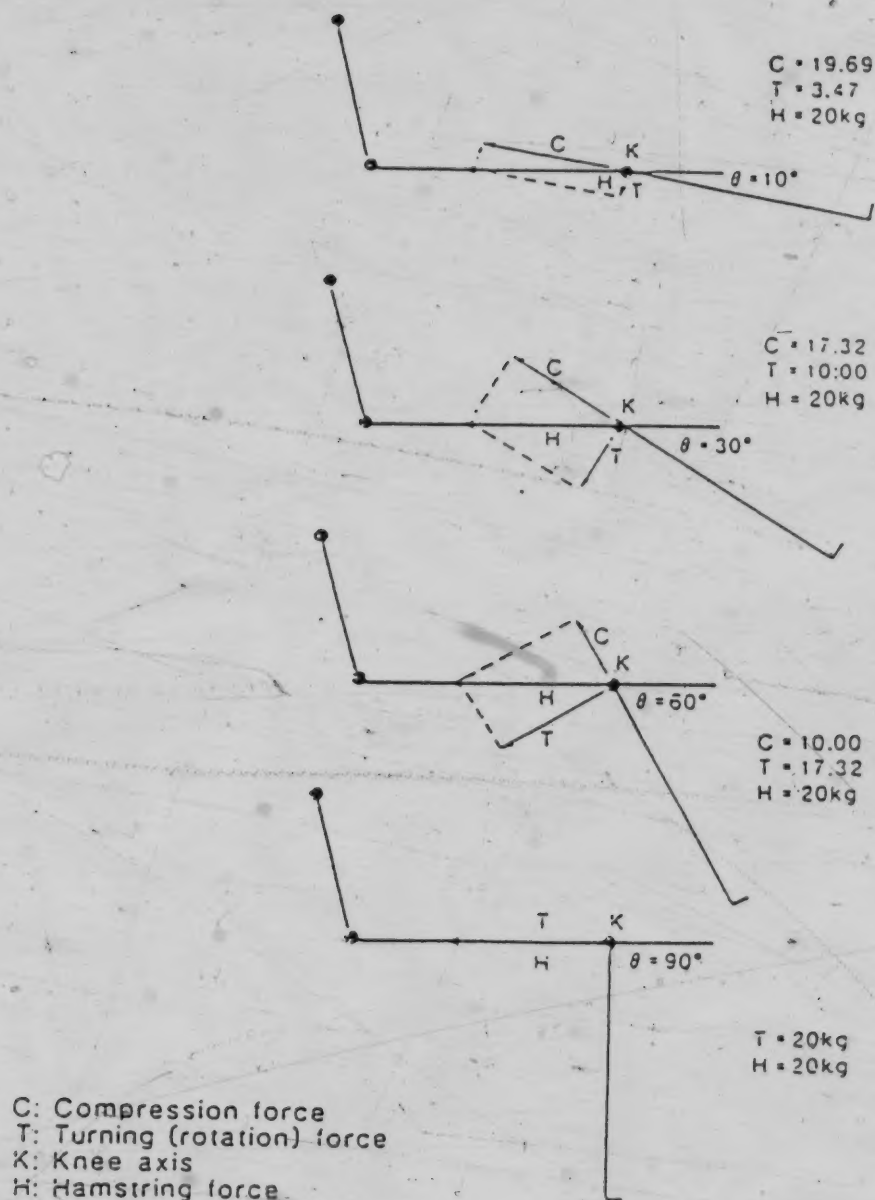


Figure 20. Resolution of forces with reference to the hamstring muscles at the four test angles used in the data analysis. The greatest turning effect on the tibia is seen with the leg at right angles to the line of action of the hamstring group

rotation at the knee (K) does not change position throughout the range of movement, (2) a constant parallel relation exists between the action line of the hamstring muscles (H) and the femur (F), and (3) the force imparted by the hamstrings is constant at all angles. Frictional and shear stresses at the knee joint are not considered in the model. It can be observed that the turning effect increases in proportion to $\sin \theta$, i.e. with the increasing angle of knee flexion, until the 90° position is reached. On this basis, therefore, one would anticipate maximum torque to be registered at the 90° angle.

Noyes and Sonstegard¹¹¹ conducted biomechanical analyses on the muscles forming the pes anserinus. Cadaver specimens were used in combination with radiographic and anatomical studies of these specimens. The gracilis, sartorius and semitendinosus muscles were separated by dissection with their origins and insertions remaining intact. The muscles were mechanically loaded with constant weights to simulate muscular contraction at several angles in knee flexion range. It was found that the flexion force of the pes anserinus and of the semitendinosus in particular increased as the angle of knee flexion increased. The data was also reported in terms of torque and the greatest flexion moment occurred at 90° , the largest angle tested. The reason for the

declining flexion force and moment at angles closer to knee extension was identified as the fact that the angle between the longitudinal axis of the tibia and the insertion of the tendon was more acute as positions nearing knee extension were assumed. A consequent decrease in mechanical advantage of the muscle acting at the knee joint was noted, despite constant loading conditions throughout range (Figure 21).

The findings of these authors were in general agreement with the biomechanical model (Figure 20) but were contrary to the findings of Smidt,¹¹⁰ who used serial x-rays and a mathematical model to calculate the instantaneous axes of rotation for the knee joint during in vivo flexion which traversed an angular displacement of 90° from full extension. The tension of the hamstring muscles was calculated by solving moment equilibrium equations. The action line for the knee flexors was assumed to be parallel to the long axis of the femoral shaft. The perpendicular distance from this line to the appropriate instant centre of rotation was considered to be the moment arm for the hamstrings (Figure 22). The mean locations of the instant centres were calculated to follow an arcuate path in a space of 3.2 cm and are depicted in Figure 23. The moment arm for the hamstring muscles taken as a whole, was calculated to be maximum in

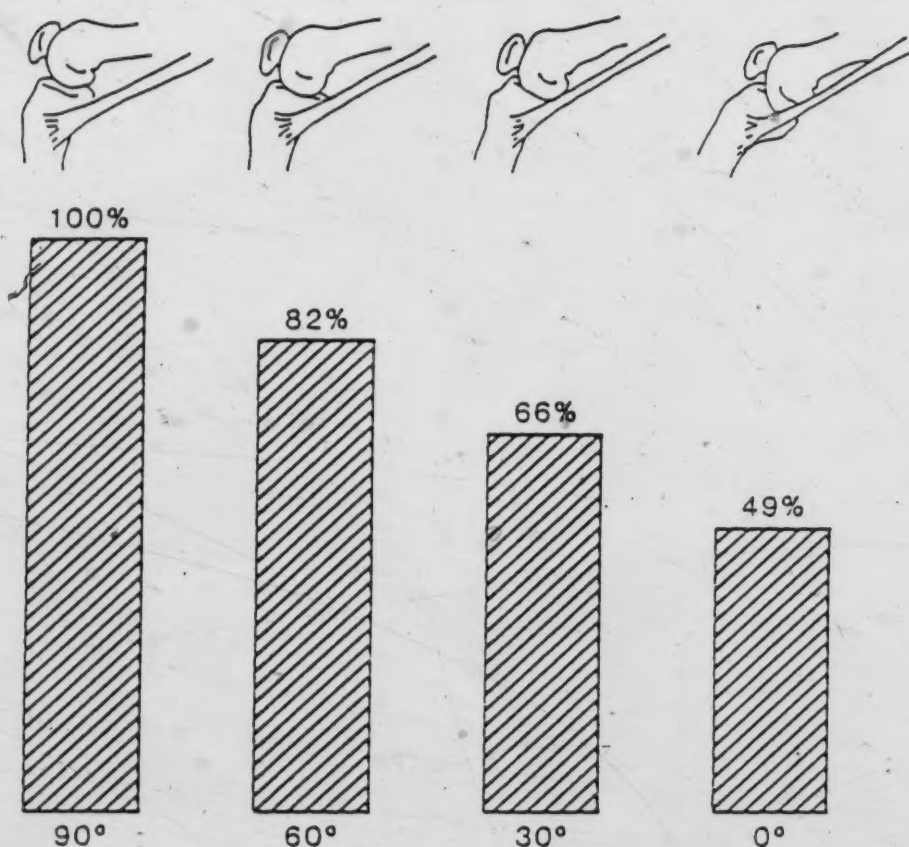


Figure 21. Pes anserinus flexion forces. Stick figures show that knee extension yields a decrease in insertion course angles with respect to the tibia. Resulting loss in mechanical advantage is indicated by reduced flexion forces with extension (modified from Noyes and Sonstegard, 1973)

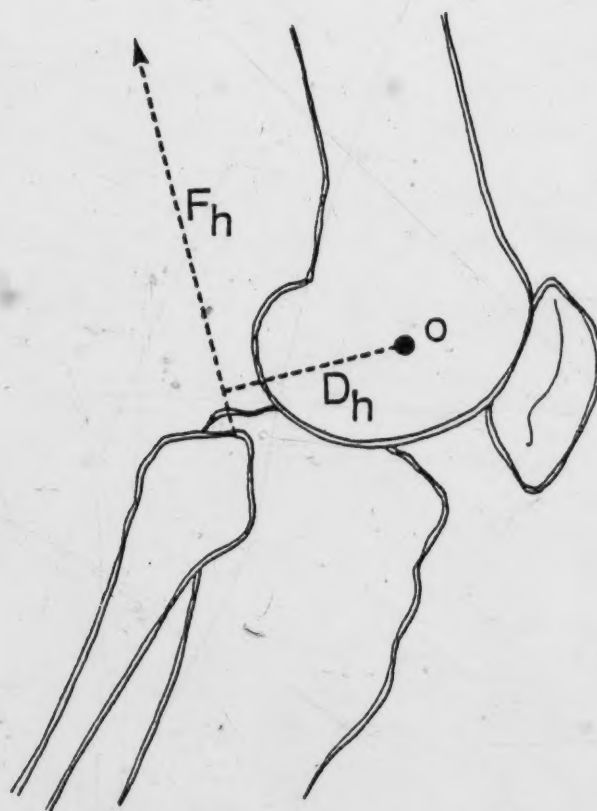


Figure 22. The moment arm for knee flexion (modified from Smidt, 1973)

F_h = Tension along the hamstring muscles
 D_h = Moment arm for hamstring muscles
o = Instant centre of rotation for the knee joint.

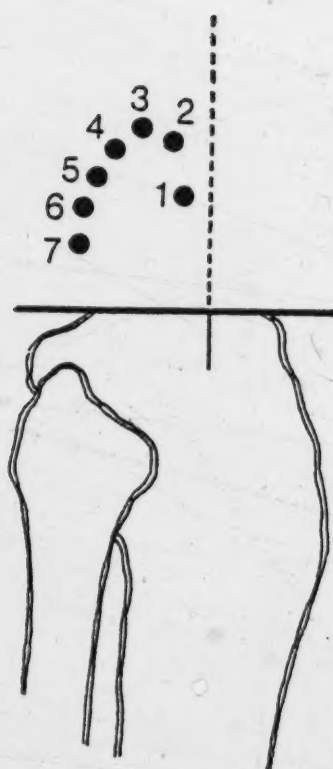


Figure 23. Pathway of instant centres with respect to the tibia and femur for the movement of knee flexion (modified from Smidt, 1973)

- 1 = 0° position
- 2 = 15° position
- 3 = 30° position
- 4 = 45° position
- 5 = 60° position
- 6 = 75° position
- 7 = 90° position

mid-range of knee flexion at 45°, increasing 1.6 cm from the position of 0° flexion to 45°, and declining the same amount between 45° and 90° of flexion. This data was used to determine that maximum torque potential for the hamstrings occurred at mid-range of flexion. Torque was defined as the force produced by the muscle multiplied by the perpendicular distance (moment arm) from the action line of the muscle to the appropriate instant centre. Smidt¹¹⁰ observed that in slow isokinetically-resisted maximal knee flexor efforts, peak torque actually occurred in the range of 20 to 35° which was earlier in range than expected from biomechanical considerations of muscle force leverage (i.e. moment arm) alterations through range. The author concluded that torque resulting from knee flexor force appeared to be affected to some extent by the physiological phenomena related to the length-tension association, more so than by moment arm and the associated biomechanical factors.

The study by Noyes and Sonstegard¹¹¹ and Smidt¹¹⁰ determined instantaneous centres of knee rotation based on the method of Frankel and Burstein.¹²⁶ However, whereas Smidt calculated a decline in the flexor moment arm at angles lesser and greater than 45° of knee flexion, Noyes and Sonstegard determined the flexor moment to increase as the tibia was positioned, increasingly toward extension.

They calculated that the instant centres moved progressively anterior as the knee extension position was approached. Nonetheless, these authors had predicted from their analytical model that a decline in pes anserinus (and semitendinosus) flexion force would occur as the knee was positioned in lesser angles of flexion. Smidt¹¹⁰ did not evidently consider the alteration in angle between the long axis of the tibia and the line of insertion of the muscle to be significant, whereas Noyes and Sonstegard¹¹¹ determined that this factor out-weighed that of flexor moment arm alteration in determining the ultimate torque capability of the muscles involved.

Despite the discord between the results of the two previous studies, it was nonetheless evident that maximal knee flexor torque would be expected to occur later in range than has been observed in situ, if only a biomechanical model is employed. Therefore, as stated by Smidt,¹¹⁰ the other main variable related to force production, that is the length-tension relationship, must be considered as a significant component of the resulting torque pattern as viewed in testing of subjects. The classical length-tension curve would predict greater total torque with the hamstring muscles relatively stretched, as would be the case with the starting positions for the isokinetic test repetitions of the present study. The

fact that maximum torque occurred near the 30° angle can be partially explained by the time lapse between the subject's commencement of the test repetition and achievement of maximal resistance against the input shaft. A second probable contributing phenomenon is the evidenced interplay between length-tension factors and muscle-force lever alterations as suggested.¹¹⁰

Hypothesis Three

3a. Previous electromyographic studies^{18,77} identified the lateral hamstrings as a selective lateral rotator of the tibia on the femur. One writer¹⁷ refuted this contention, stating that EMG activity was present in both heads of the biceps femoris muscle during lateral tibial rotation, in less than one-half of subjects tested. The overall main effect for position was found to be statistically significant in the present investigation ($P < 0.001$). Tukey's post-hoc procedure detected statistical significance ($P < 0.05$) to lie in the comparison between %IEMG in external rotation versus internal rotation. When the isokinetic repetitions were performed with external tibial rotation (Figure 13) 25.3% greater IEMG was elicited, compared to repetitions with internal rotation. Between the positions of external rotation and

normal rotation, only a 10.3% difference existed, again in favor of the position of external rotation. This difference was not statistically significant. The mean IEMG amplitude decreased 15.1% with internal rotation compared to normal rotation. This difference did not achieve statistical significance.

The present findings support the concept that lateral hamstrings activity is influenced by the position of the tibia during resisted knee flexion. However, the results do not concur with the suggestion that isokinetically-resisted knee flexion combined with external rotation of the tibia will successfully isolate the lateral hamstrings. No statistically significant difference in IEMG amplitude was found between the positions of external rotation and normal rotation. Thus, the present findings indicate that the traditional form of hamstring exercise, represented in this study by the test movement performed in the position of normal rotation, is equally effective in evoking lateral hamstring activity.

The amount of available range into internal and external tibial rotation was shown in previously published articles^{8,9,114} to increase as the angle of knee flexion increased. Based on this information, it was postulated that the IEMG recorded from the lateral hamstrings during the three test movements would show smaller differences

early in knee flexion range. This reckoning was confirmed, as is visually evidenced in Figure 17. The mean electromyographic amplitude was virtually equal for the lateral hamstrings at the 10° angle, when the positions of external rotation and normal rotation were compared. Inspection of the IEMG amplitude at 30° showed a 16.1% difference, and a 19.8% contrast at the angle of 60°. Consequently, it was decided that a supplementary ANOVA would be valuable to investigate the possibility that statistically significant differences might be found between these positions when the data from the earliest measured angle was removed from the statistical analysis. Also, such a statistical procedure would allow a more meaningful comparison to be made to the literature²⁰ which recommended isokinetic knee flexion exercise with the tibia externally rotated, starting at a knee angle of 20°. The supplementary ANOVA and subsequent post-hoc analyses indicated similar results to the primary analyses. Specifically, no statistically significant difference in %IEMG was found when the positions of external and normal rotation were compared. In the initial analysis, a difference of 4.3% IEMG activity was observed at the 90° angle, when external and normal rotations were compared (Figure 17). Similar to the 10° angle, the difference in IEMG amplitude was extremely

small, compared to that found both at 30° and 60°. This observation prompted a further supplementary ANOVA which deleted the data from the 10° and 90° angles. Hence, a two-way ANOVA was conducted with only the central two levels of the angle factor: 30° and 60°. However, as for the previous analyses, no statistical significance was found. Thus, the electromyographic evidence gathered from the biceps femoris muscle in the present investigation does not lend support to the contentions of previous authors that the biceps femoris muscle can be isolated during isokinetic knee flexion exercise.

3b. Figure 14 compares the main effects for tibial position on the IEMG activity of the medial hamstrings. Overall statistical significance was found ($P < 0.001$). Post-hoc pairwise contrasts located statistical significance in IEMG amplitude between the positions of external and internal rotation and between normal and external rotation ($P < 0.005$). Mean IEMG amplitude in internal rotation exceeded that for external rotation by 15.6%. Values for the normal rotation position were 9.7% higher than for external rotation. Mean IEMG activity in internal rotation was found to be only 5.9% greater than the activity elicited in normal rotation. This contrast was not statistically significant.

The results for the medial hamstring muscles indicate

that tibial rotation does effect the amplitude of electrical activity elicited from the muscles, as was the case for the lateral hamstring muscle. The fact that only a 5.9% difference was found between the activity in normal and internal rotation, contravenes the assumption that the medial hamstring muscle is activated substantially more in a combined knee flexion-internal rotation exercise than in a traditional knee flexion routine.

Davies¹⁹ proposed that rehabilitation for anteromedial instabilities of the knee would benefit from an exercise which involved isokinetic knee flexion from 20° to 120°, with the tibia held in internal rotation. The objective of the tibial rotation was to isolate the semimembranosus and semitendinosus muscles during the activity. In order to facilitate a more direct comparison to the literature, a supplementary ANOVA was conducted deleting the data gathered at the 10° angle. As is demonstrated in Figure 18 only a 1.0% difference in mean IEMG amplitude was observed in comparing the positions of internal and normal rotation at the 10° angle. This negligible difference may have, in part, reflected the small amount of tibial rotation available in early knee flexion.

The results of the supplementary ANOVA did not differ from those of the original analysis. Hence the rationale

expressed in the cited literature¹⁹ was not supported by the present findings. Other acknowledged medial rotators of the tibia were not investigated for electromyographic activity during the test movements. A quantitative electromyographic study of these muscles would be needed to more completely assess the activity of all medial rotators of the tibia during the prescribed test movements. The anatomical alignments of the gracilis and sartorius muscles have been shown in cadaver studies to be superior to that of the semitendinosus muscle in providing mechanical advantage for purposes of internally rotating the tibia.¹¹¹ The popliteus muscle has been demonstrated by electromyography to be a medial rotator of the tibia in various circumstances, but none closely approximating the conditions of the present study.⁶⁹

The present findings indicate that the electrical activity of the medial and lateral hamstrings can effectively be modified by utilizing the extremes of tibial rotation during isokinetic knee flexion exercise. The lateral hamstring muscle activity was markedly less when internal tibial rotation was incorporated into the test movement, compared to when external rotation was used. Conversely, the IEMG of the medial hamstring muscle was substantially reduced in external rotation when compared to either normal rotation or internal rotation.

These comparisons were all significant, statistically.

Manual muscle testing books^{4,5} demonstrated the examination procedures for the biceps femoris and the medial hamstrings. Both manoeuvres were performed with the patient in prone lying. The actual angle of the knee was not specified in either manual, although Kendall and McCreary⁵ suggested a knee angle less than 90° with knee extension equal to 0°. For testing the biceps femoris, the tibia was aligned in external rotation. Examination of the medial hamstrings was conducted with the tibia internally rotated. For both groups, resisted knee flexion was performed following the appropriate tibial alignment, just described. The mode of resistance, i.e. isometric, isotonic, or isokinetic, was not stipulated.⁵

The present results lend support to the prescribed muscle tests used for selectively testing the lateral and medial hamstring muscles, especially if the tests are performed through knee flexion range at a relatively constant velocity with the examiner's resistance matching the patient's torque production throughout range. The following logic is offered to support this claim.

In the present study, the incorporation of external tibial rotation into the test movement caused a substantial, and statistically significant, decline in medial hamstring activity compared to that produced either

in normal rotation or internal tibial rotation.

Therefore, by decreasing medial hamstring activity, the biceps femoris muscle was focused upon. Reciprocally, incorporation of internal rotation was associated with a reduction in biceps femoris activity compared to that produced in external rotation. This reduction served to place the focus on the medial hamstring muscles. Thus, the effect of tibial rotation on the medial and lateral hamstrings activity was to selectively place an emphasis on one of the hamstring groups by causing a decrease in the activity of the other group, rather than increasing the activity of the "isolated" hamstring muscle.

3c. There were no statistically significant main effects for tibial position on the gastrocnemius muscle. The results are graphed in Figure 15. No literature has been published with regard to the gastrocnemius muscle as a selective rotator of the knee, and therefore, no difference in IEMG was anticipated. In order to determine any selective activity present, the medial and lateral heads of the muscle would have to be monitored separately, most probably employing wire electrodes, due to the close proximity of the muscle bulk of the two heads. The set-up of the present study treated the gastrocnemius muscle as a whole by placing the surface electrodes in parallel alignment with the muscle fibres, in the region where the

medial and lateral heads met.

Hypothesis Four

The main effects for tibial position on torque achieved overall statistical significance and are displayed in Figure 16. Torque production during isokinetic knee flexion exercise in combination with varied positions of tibial rotation, has not previously been researched. The pairwise post-hoc comparison between normal rotation and external rotation proved to be statistically non-significant. However, the mean torque for both positions was greater than that produced in the position of internal rotation ($P < 0.05$). A difference in torque of 7.5% was found between the positions of normal rotation and internal rotation, and a 6.7% difference was determined between the positions of external and internal rotation.

A factor which may have figured prominently in these results was that of movement pattern familiarity. The test position of tibial internal rotation and ankle dorsiflexion followed by isokinetically-resisted knee flexion was, for most subjects, the least familiar movement combination employed in the study. During the practice sessions, prior to test day, trials often

involved repetitions of this movement pattern beyond the required minimum. The additional repetitions were performed usually at the request of the participants. Physical discomfort was never a complaint and therefore cannot be considered as a contributing factor in the observed decline in torque during knee flexion with internal rotation. Two studies^{10,16} demonstrated that the free hanging tibia tended to assume a "neutral" position, which was in some degree of external rotation, relative to the sagittal plane. The position of normal rotation employed in the present investigation, permitted the tibia to find its natural degree of torsion with respect to the femur. During knee flexion the tibia was observed to lie in some degree of external rotation. In later ranges this tendency was not as obvious. Because of the observed propensity for the tibia to align itself in external rather than internal rotation, it would appear reasonable to assume that the present test movement which incorporated external rotation was a more natural movement combination than the test movement which included internal tibial rotation.

Muscle strength depends on the number of motor units activated and their frequency of excitation.²² It would, therefore, appear logical that a decrease in motor unit activity would be found in conjunction with a reduction in

muscular force or torque. A decline in motor unit activity would be reflected by reduced IEMG amplitude, as detected by surface electromyography. In the present experiment maximum torque was produced in the position of normal rotation. This position was also the position in which maximum mean %IEMG amplitude was found when the amplitudes from all muscle groups were added (Table 17). The electromyographic activity of the knee flexors, taken collectively, decreased by a net total of 16.2% in internal rotation, compared to normal rotation. The %IEMG reduction compared to a 7.5% reduction in torque. The collective %IEMG amplitude declined by only 9.4% in external rotation, compared to normal rotation, accompanied by a 0.8% decrease in torque. A comparison of the positions of external and internal rotation revealed a mean torque difference of 6.7% ($P < 0.05$), with the torque in external rotation being greater. The mean %IEMG in external rotation was 6.8% greater than for internal rotation. It appears, therefore, that the larger reduction in electromyographic amplitude associated with the position of internal rotation was at least partly responsible for the concomitant decline in torque observed.

A complete understanding of the operatives contributing to torque reduction found in the test

Table 17. Mean %IEMG totals related to tibial position

<u>Dependent Variable</u>	<u>External Rotation</u>	<u>Normal Rotation</u>	<u>Internal Rotation</u>
%Torque	62.7	63.5	56.0
%IEMG Gastrocnemius	98.6	108.6	101.5
%IEMG Lateral Hamstrings	95.4	85.1	70.1
%IEMG Medial Hamstrings	73.2	82.9	88.8
%IEMG Totals	267.2	276.6	260.4

movement which incorporated internal tibial rotation would require knowledge of the concurrent alterations in muscle lever lengths of the knee flexors, changes in muscle action lines related to the tibia, and determination of muscle length-tension characteristics of each muscle involved. The possibility of neurophysiological mechanisms contributing to torque modification must also be considered. In terms of the present research design, these factors were indeterminate.

Interaction Effects

The unique joint effect of two or more independent variables is termed an "interaction".¹²⁴ Graphical evidence of significant interaction would be manifested by the departure from a parallel relation.

The present study found overall statistical significance on interaction for all three muscle groups. The interaction effects on mean %IEMG for the lateral hamstring muscles are presented in Figure 17. The greatest divergences from parallelism in the figure are observed between 10° and 60° and 10° versus 90° in the position of external rotation, as well as between 10° and 60° in normal rotation.

For the medial hamstring muscles (Figure 18),

deviation from parallelism is most apparent between 10° and 60° in the position of external rotation, and 10° versus 60° in internal rotation. It is suggested that these comparisons were most accountable for the statistically significant overall interaction for the medial hamstring group.

Interaction effects for the gastrocnemius muscle are graphed in Figure 19. The marked divergence from parallelism between 10° and 90° in normal tibial rotation, 10° and 90° for external tibial rotation, and 10° versus 90° , and 30° versus 90° for the position of internal tibial rotation may have been partly responsible for the statistically significant overall interaction reported in Table 9.

CHAPTER SIX

CONCLUSIONS

The present study was conducted to examine the IEMG and torque values associated with maximal effort isokinetic knee flexion while the tibia was positioned in each of three rotational postures: normal rotation, external rotation, and internal rotation. The muscles of primary interest were the medial and lateral hamstring groups. The gastrocnemius muscle was also examined.

The raw scores for the 19 healthy female subjects were transposed into percentage scores compared to a reference activity established for each muscle. The data were then subjected to a two-way analyses of variance with repeated measures on both factors: tibial rotation and knee angle. Significant main effects were subjected to post-hoc analyses using the Tukey procedure.

The results of the study supported the following conclusions:

1. The %IEMG comparisons for lateral and medial hamstring muscles were statistically nonsignificant ($P < 0.05$) for comparisons between values measured at 30°, 60° and 90° of knee flexion. Thus, the EMG-muscle length

relationship of striated muscle, as established in the literature, was not adhered to by these muscles.

Indeterminate variables such as mechanical leverage may have influenced the electromyographic amplitudes recorded.

2. The %IEMG comparisons of the gastrocnemius muscle for knee angle were significant overall ($P < 0.001$) as determined by the ANOVA. Post-hoc comparisons were significant between 10° and 30° , 10° and 60° , 10° and 90° and 30° versus 90° . The comparison between 60° and 90° approached but did not achieve statistical significance ($P < 0.05$). These results indicated that the EMG-muscle length relationship for the gastrocnemius muscle in the present investigation conformed closely to that established in the literature.
3. Relative torque values related to knee angles, were statistically significant overall ($P < 0.001$) as established by the ANOVA. Post-hoc analyses were statistically significant for comparisons at 10° versus 30° , 10° versus 60° , 30° versus 90° , and 60° versus 90° . Of the angles examined, peak torque occurred at 30° . The location of peak torque and overall contour of the torque recordings were in general agreement with the reported literature.

4. The IEMG and torque data reported here are offered as norms for non-athletic females in the age range of 21 to 35 years.
5. Biomechanical models predicted maximum torque to occur later in knee flexion range than was evidenced in the present study and in the cited literature. This discrepancy was attributed to the influence of muscle force lever and the length-tension relationship of striated muscle.
6. The statistical comparisons of %IEMG values related to tibial position were significant overall ($P < 0.001$) as determined by the ANOVA, for lateral and medial hamstring muscles. However, comparisons between external and normal rotation, for the lateral hamstrings, and between internal and normal rotation, for the medial hamstring muscles, were not statistically significant ($P < 0.05$). Thus, no statistical support could be given to the concept that selective rotation of the tibia, when combined with isokinetic knee flexion, effectively isolates the lateral or medial hamstring muscles.
7. The amplitude of IEMG for the lateral hamstring muscles was significantly reduced when isokinetic knee flexion was combined with internal rotation of the tibia, compared to the mean %IEMG registered in knee

flexion combined with external tibial rotation. The %IEMG of the medial hamstring muscles was reduced during the combination of knee flexion and external rotation, compared to the knee flexion-internal rotation combination ($P < 0.05$). Hence, the practice of positioning the tibia into external and internal rotation to selectively test the lateral and medial hamstring groups, respectively, was supported by the present findings.

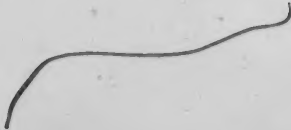
8. Isokinetic torque was reduced when the tibia was held in internal rotation, compared to the %torque recorded in normal rotation ($P < 0.05$). The reduction in torque appeared to be at least partly related to the concomitant reduction observed in electromyographic activity.

Recommendations

The primary recommendations which can be made from the present investigation are:

1. The same research design be duplicated, using a larger sample size to verify the present findings.
2. A similar study be conducted, examining other known knee flexors and tibial rotators, such as the

popliteus, gracilis, sartorius, and tensor fascia latae muscles.

3. Further investigation into the relative importance of IEMG and torque production during exercise for the desirable result of maximal strength gains.
 4. An investigation of similar design to the present study, to determine any sex-related differences in IEMG patterns for the hamstring muscles.
 5. A study be done, using the same test movements, to compare the IEMG associated with relatively slow isokinetic velocities, such as that used for the present investigation, to the IEMG recorded during greater velocity repetitions, such as those commonly employed in the clinical setting.
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APPENDIX 1

INFORMED CONSENT FORMS

Faculty of Rehabilitation Medicine
Department of Physical Therapy
University of Alberta
Edmonton, Alberta

Informed Consent Form For Research Study:

"The Effect of Tibial Rotation on Isokinetic
Knee Flexion: An EMG Study"

The hamstring muscles are widely acknowledged as being rotators of the knee joint. Few studies have been conducted to determine the contributions of these muscles to knee rotation. One method of examining the muscles is by using electromyography. Electromyography involves detection of the electrical activity which a muscle generates when it contracts.

The study in which you are being asked to participate will involve a practice session (approximately 45 minutes) and a test session (approximately 1 hour and 45 minutes to 2 hours) performed on separate days. You will be asked to carry out several repetitions of isokinetic knee flexion on the Cybex II isokinetic apparatus. One warm-up (submaximal) repetitions will be followed by three maximal efforts for each test movement.

There are 3 test movements (1) knee flexion with no attempt on your part to control rotation of the tibia (2) knee flexion with full active internal rotation throughout range (3) knee flexion with full active external rotation of the tibia throughout range. A short 30 second rest period will be provided between each practice repetition and a minute interval between each test repetition to allow recuperation. All repetitions will be performed in a sitting position.

The electrical activity generated by the muscles will be detected by small electrode discs placed on the surface of each subject's skin. They will be held in place with adhesive tape. To ensure proper placement of the discs, two muscle groups (the medial and lateral hamstrings) will be stimulated with a faradic electrical current. In this way the motor point of each muscle group can be located.

The risk to the subjects is minimal. The knee flexor muscles may become sore for a short period of time following the test procedure. The occurrence of muscle

soreness is a normal response to exercise. The use of surface electromyography is very safe and comfortable and is a commonly used investigative tool. Faradic stimulation is commonly used in investigations as well as therapeutically. Some individuals find faradic stimulation to be slightly uncomfortable initially. It will be employed only briefly to locate the motor point of the muscle, and should be quite comfortable. It must be stated that any electrical equipment carries with it some risk. The equipment used in studies such as this one is extremely safe.

Any questions you may have before, during or after the session will be gladly addressed.

The subject has the right, at any time, to withdraw from the study for any reason.

All information and data collected during the study will become the property of the Department of Physical Therapy, University of Alberta. Access to the information will be restricted to those conducting the study.

Please retain this explanation for your own records.

Thank you.

In the event that questions concerning the study arise, please feel free to contact Dan Boland, at 432-2068 (work) or 436-2843 (home).

Department of Physical Therapy
Faculty of Rehabilitation Medicine

University of Alberta
1985

INFORMED CONSENT FORM FOR INVESTIGATIVE STUDY

The Effect of Tibial Rotaton on Isokinetic
Knee Flexion: An EMG Study

Subject Consent (retained by investigators)

I _____ do hereby agree to
(PLEASE PRINT NAME)
participate as a subject in the study entitled "Sel-
ectivity of the Hamstring Muscles During Isokinetic Knee
Flexion: An EMG Study" to be conducted by Daniel Boland,
B.Sc. (PT) under the supervision of Dr. J.F. Kramer.

The nature of this study has been explained to me and I
understand that I may withdraw from participation at any
time.

SUBJECT'S SIGNATURE

DATE

ADDRESS

PHONE NUMBER

I was witness during the explanation referred to above and
to the signature of the subject.

WITNESS' SIGNATURE

DATE

Faculty of Rehabilitation Medicine
Department of Physical Therapy
University of Alberta
Edmonton, Alberta

Informed Consent Form For Invasive Procedure
in Conjunction with Research Study:

"The Effect of Tibial Rotation on Isokinetic Knee Flexion:
An EMG Study"

One procedure involved with the present investigation involves the simultaneous detection of electromyographic signals, within the lateral and medial hamstring muscle groups, using surface electrodes and wire electrodes. A 26.5 gauge needle is employed to pierce the skin and to enter the muscle tissue to an approximate depth of 1 centimetre. Two such penetrations are required: 1 for the lateral hamstrings and 1 for the medial hamstrings. When the needle is withdrawn, 2 fine wire electrodes will remain embedded in the muscle until completion of the procedure. The wire insertions will be performed by Dr. J.F. Kramer, Thesis Supervisor.

When the surface and wire electrodes have been appropriately applied, you will be asked to perform a number of test movements. There are 3 test movements (1) knee flexion with no attempt on your part to control rotation of the tibia (2) knee flexion with full active internal rotation throughout range (3) knee flexion with full active external rotation of the tibia throughout range.

After these test movements have been completed, the surface electrodes will be removed and the wire electrodes carefully withdrawn from the muscle substance.

The risk to the subject is minimal. However, as with any procedure which involves piercing of the skin, a small possibility of infection exists. Every precaution will be taken to minimize this possibility. In addition, any use of electrical equipment, such as the EMG apparatus, carries with it a minimal risk. The equipment to be used in this study has been designed and proved to be very safe. Local muscle soreness, from the muscular efforts and from infiltration by the wire electrodes may be experienced. This soreness, if it does occur, will likely be of a short duration.

The total procedure will involve about 1 hour of your time.

The subject has the right, at any time, to withdraw from this test procedure.

All information and data collected during the study will become the property of the Department of Physical Therapy, University of Alberta. Access to the information will be restricted to those conducting the study.

Please retain this explanation for your own records.

Thank you.

In the event that questions concerning the study arise, please feel free to contact Dan Boland, at 432-2068 (work) or 436-2843 (home).

Department of Physical Therapy
Faculty of Rehabilitation Medicine

University of Alberta
1985

INFORMED CONSENT FORM FOR INVESTIGATIVE STUDY

Procedure in Conjunction with the Research Study:

"The Effect of Tibial Rotation on Isokinetic Knee Flexion:
An EMG Study

Subject Consent (retained by investigators)

I _____ do hereby agree to
_____ (PLEASE PRINT NAME)
participate as a subject in the investigative procedure
involving recordings of surface and wire electromyography
of the lateral and medial hamstring muscles, to be
conducted by Daniel Boland, B.Sc. (PT) and by John F.
Kramer, Ph.D.

The nature of this study has been explained to me and I
understand the potential risks and that I may withdraw
from participation at any time.

SUBJECT'S SIGNATURE

DATE

ADDRESS

PHONE NUMBER

I was witness during the explanation referred to above and
to the signature of the subject.

WITNESS' SIGNATURE

DATE

APPENDIX 2

INSTRUMENTATION CALIBRATION

VALIDITY: CALIBRATION METHOD

Calibration is the determination of accuracy of an instrument to a known scale or standard unit. The instrument's measuring ability may drift from accuracy because of constant use, age, handling and abuse of the instrument by users, maintenance given the instrument during its life-span and environmental conditions which surround the instrument during its operations.

Hewlett Packard 7754A Recorder

(a) The four channels of the Hewlett Packard heat-sensitive pen recorder were calibrated individually by establishing linearity of pen deflection, i.e. "output" when compared to "input" stimuli. The input stimulus was provided by an amplitude calibration and comparator, Tektronix model 0670502.* The term "linearity" refers to the degree to which output variations agree with the input variations of an instrument. A sample of calibration is provided in Figure 24 of this appendix. Coefficients of validity and reliability are presented in Table 18. Channel 1, the torque channel, had a gain of 5 volts peak

* Calibration Fixture: Amplitude Calibrator and Comparator
(Serial number: 067050201) Tektronix, Portland, Oregon,
U.S.A.

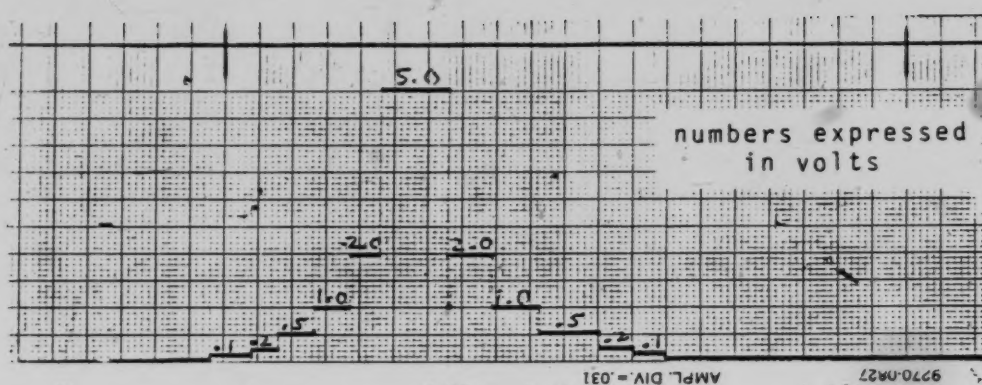


Figure 24. Hewlett Packard 7754A Recorder calibration sample

Table 18. Pearson product moment correlations for validity
and reliability of the Hewlett Packard 7754A
Recorder

<u>True Input</u>	<u>Trial 1</u>	<u>Trial 2</u>
0.1	1.0	1.0
0.2	2.0	2.0
0.5	4.9	5.0
1.0	9.9	9.9
2.0	19.1	19.1
5.0	49.9	49.9

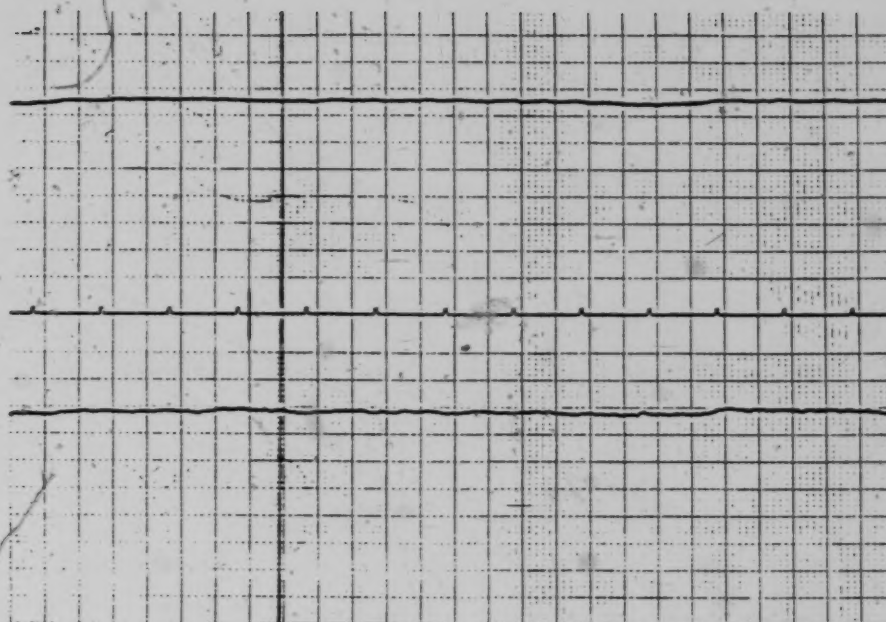
$$r_v = .99983$$

$$r_r = 1.00000$$

torque. Channels 2, 3, and 4, the electromyography channels, each had a gain of 0.2 volts. The upper cutoff frequency was set at 300 Hz and the lower cutoff frequency at .05 Hz.

(b) Chart recorder speed constancy was very important during testing procedures to ensure optimal accuracy of angular measurements which were calculated from the chart. In order to establish chart speed constancy two procedures were followed. First the solenoid of the recorder time marker was monitored and displayed on a Tektronix model 5441 storage oscilloscope.* The time base was expanded to equal 0.2 s per division of the oscilloscope grid. One complete cycle equal to 1 s. Accuracy of the time marker impulses was then determined by direct measurement on the storage oscilloscope. Having determined the accuracy of the time marker impulse signal at one second intervals these intervals were registered and recorded the chart speed was set at 5 mm/s. The intervals were then measured directly and proved to be equal. The constancy of chart speed was thereby verified (see Figure 25).

* Tektronix 5441 Storage Oscilloscope. Tektronix Inc., Beaverton, Oregon, U.S.A.



* The equal distances between the raised marks indicate a constant chart speed

Figure 25. Hewlett Packard 7754A Recorder chart speed calibration sample

Cybex II Isokinetic System

The Cybex II Isokinetic system was calibrated by attaching known weights to the end of the Cybex mechanical lever arm. The weights used for the calibration were provided by the Cybex company and were claimed to be accurate within 0.001 lb.

The weights were added in increments of 2.5 lb throughout the torque range expected during the study, i.e. 40 ft lb to 100 ft lb. Hence, torque was incremented at intervals of 5 ft lb, using a 2 ft distance for the mechanical torque arm (see Table 19).

The lever arm moved isokinetically through the test range to be used, at a velocity of 3 RPM, which was also the velocity used during testing. The resultant pen deflections on the torque channel of the Hewlett Packard recorder were registered. Subsequently, direct measurements made from the chart paper determined linearity between input and output registrations. Sample recordings and determinations of validity and reliability coefficients are provided in Figure 26 and Table 20, respectively.

Table 19. Data collection for validity and reliability studies of the
Cybex II isokinetic system

<u>TORQUE</u>		<u>UNITS OF DEFLECTION</u>	
		<u>Trial A</u>	<u>Trial B</u>
1.	50 (ft lb)	18.5	18.0
2.	55.0	19.5	20.0
3.	60.0	21.0	21.0
4.	65.0	22.9	23.0
5.	70.0	24.0	25.0
6.	75.0	26.0	26.0
7.	80.1	28.0	28.0
8.	85.1	29.0	29.5
9.	90.1	31.0	30.9
10.	95.1	33.5	34.0
11.	100.1	35.5	35.0

Length of Lever = 2.0013 ft (24.015 inches)

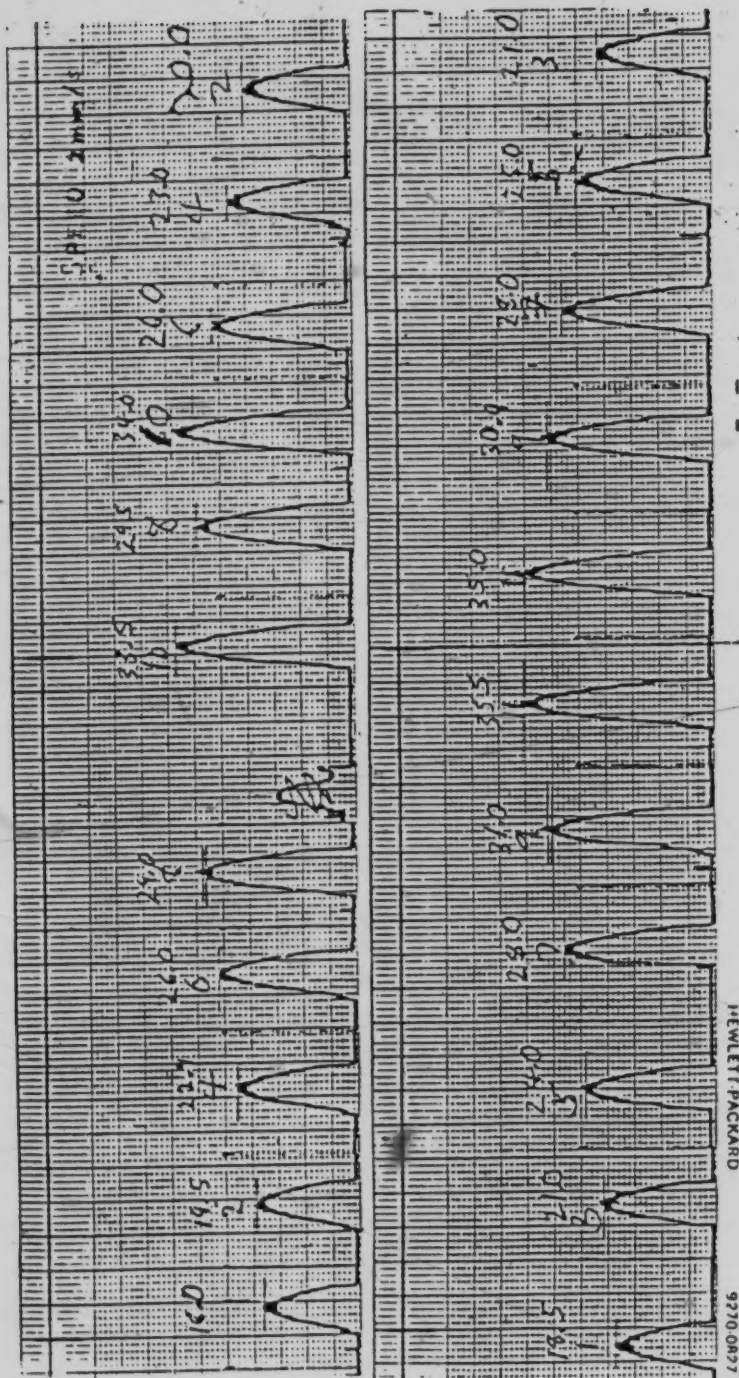


Figure 26. Torque channel registrations for purposes of validity and reliability calibrations

Table 20. Pearson product moment correlations for validity and reliability of the Cybex II isokinetic system

True Input (ft lb)*	Trial 1	Trial 2
1. 50.0	18.5	18.0
2. 55.0	19.5	20.0
3. 60.0	21.0	21.0
4. 65.0	22.9	23.0
5. 70.0	24.0	25.0
6. 75.0	26.0	26.0
7. 80.1	28.0	28.0
8. 85.1	29.0	29.5
9. 90.1	31.0	30.9
10. 95.1	33.5	34.0
11. 100.1	35.5	35.0

$$r_v = .99648$$

$$r_r = .99678$$

* Rounded off to nearest 0.1 ft lb

Leaf Electronics System VII Electromyograph Four-Channel Amplifier

Calibration of this system was determined by the use of a Hewlett Packard model 3312A function-generator.* A Tektronix model 5441 storage oscilloscope was employed to record and measure the amplitude and frequency of the waves generated. To test the calibration of the system, two procedures were carried out. For the first procedure, signals from the frequency generator were simultaneously directed (a) through amplifier 1 of the Leaf System, i.e. bypassing the transponder unit into the rectified output component. From there, the signal was directed into channel 1 of the oscilloscope, (b) directly into the second channel of the oscilloscope. The frequency generator dial generated frequencies of 0 Hz to 10 KHz. Linearity of the amplifier was confirmed if the amplitude of the channel 1 oscilloscope channel remained virtually constant. An example is provided in Figure 27.

The second procedure involved comparison of two "artifact rejection frequency response curves". One of these was generated by the function generator. The second curve was provided as a criterion measure by the Leaf Electronics System VII EMG operation manual. The accuracy of the system was confirmed by comparison of the frequency

* Hewlett Packard 3312A Function Generator. Hewlett-Packard (Canada) Ltd., 11620A - 168th Street, Edmonton, Alberta T4M 3T9.

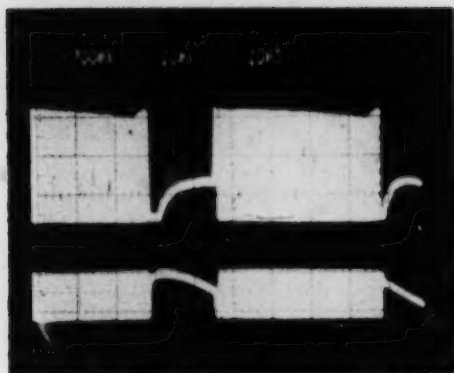


Figure 27. Calibration check for linearity of
Leaf Electronics System VII four-channel
Electromyograph amplifier

response curve recorded by the investigator and that provided by the manufacturer in the operations manual. As stated in the manual, if accurate calibration is to be achieved, it should be accomplished in the filter position which was used in the experiment. The pre-shipment calibration was done with the transponder, i.e. pre-amplifier unit, in the "selective" position. This is the filter position, according to the manufacturer, which is appropriate when it is not possible to negate 60 Hz interference pattern in a laboratory setting, and thus was used for the present experiment.

To summarize, the second procedure included the transmission of signals from the frequency generator simultaneously directed (a) along the electrode lead wires through the transponder then into the first channel of the Leaf System amplifier. From there the signal was directed into channel 1 of the oscilloscope. The result was a twice amplified rectified signal; (b) directly into the second channel of the oscilloscope. As stated by the manufacturer the transponder unit, when switched to the "selective" setting is designed to amplify the signals found in the 420 Hz range optimally. Above and below this frequency range the signals are attenuated. Therefore, the proper signal form, as described and illustrated by the manufacturer is presented in Figure 28a. Figure 28b is a sample of the signal generated for purposes of the

ARTIFACT-REJECTION FREQUENCY RESPONSE CURVE OF REMOTE TRANSPONDER UNIT.
E.M.G. SYSTEM VII

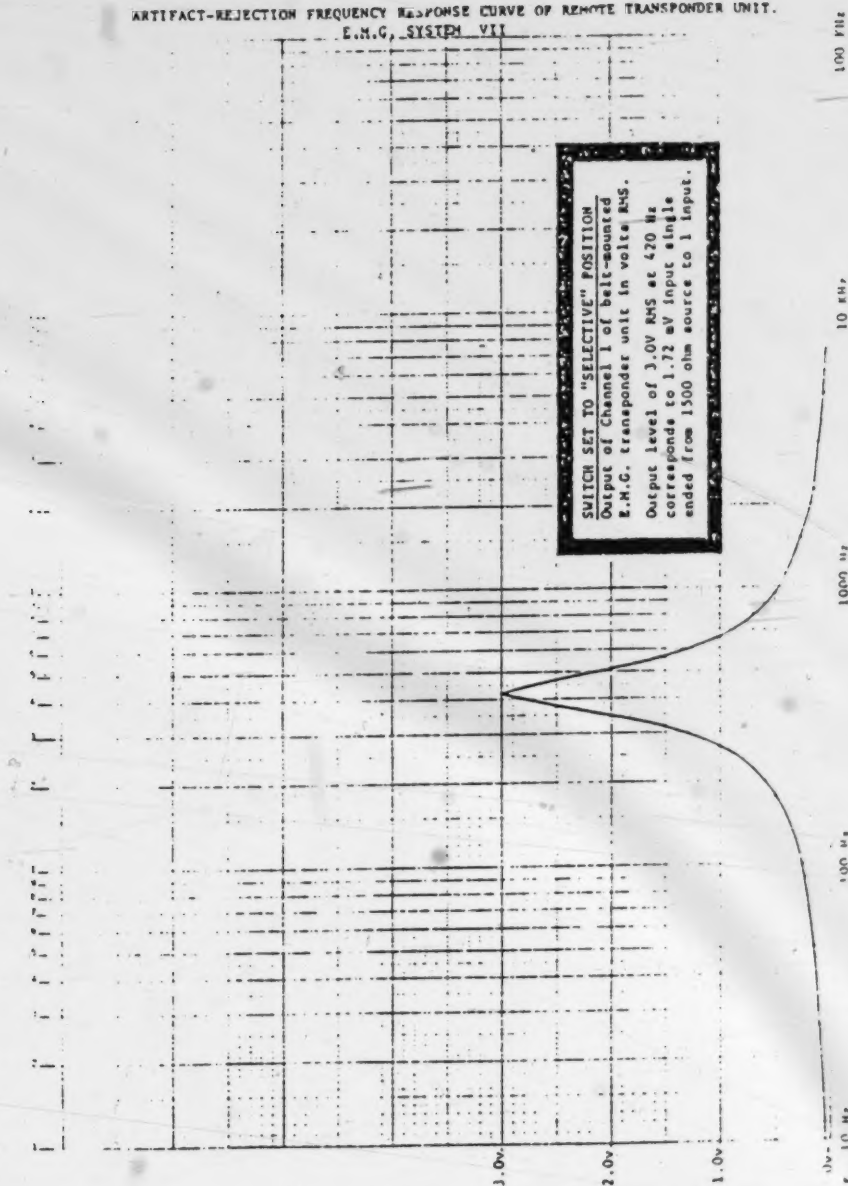


Figure 28a. Artifact-rejection response curve of transponder unit as demonstrated by the manufacturer

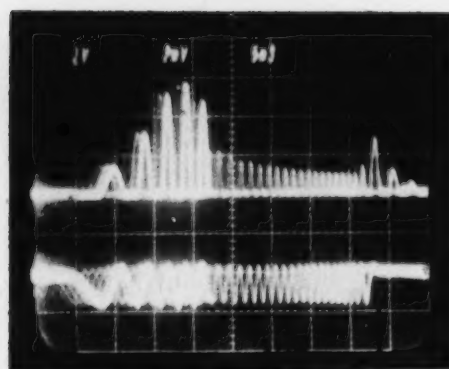


Figure 28b. Artifact-rejection response curve of transponder unit as demonstrated by investigator

comparison required for calibration. A block diagram of the calibration system is presented in Figure 29. Both calibration procedures, i.e. procedure one and procedure two were carried out on all four amplifier channels of the Leaf System.

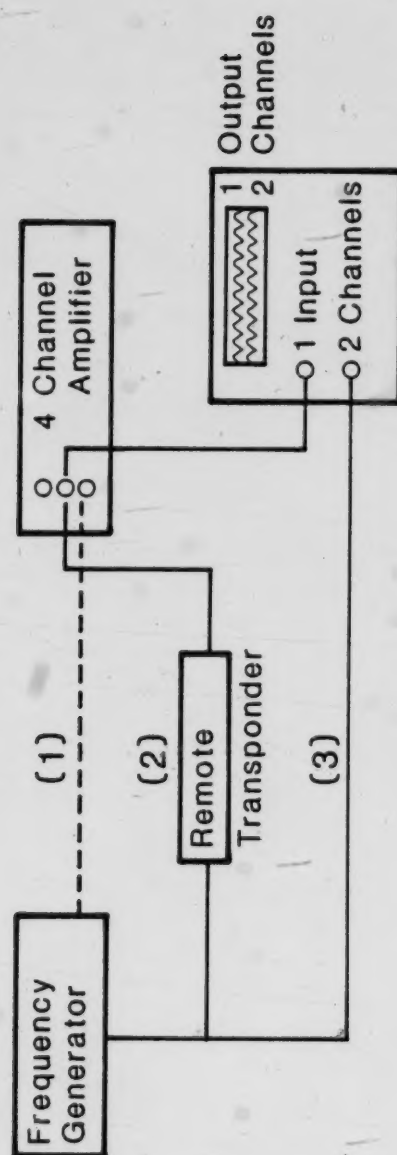


Figure 29. Block diagram of Leaf System VII Electromyograph Four Channel Amplifier calibration check.

- (1) designates pathway (a) for the first calibration check
- (2) designates pathway (a) for the second calibration check
- (3) designates pathway (b) for both calibration checks

APPENDIX 3

RELIABILITY COEFFICIENTS

INTRA-RATER RELIABILITY

Measurements were taken from the chart recordings, by the investigator, for purposes of calculating the intra-rater reliability coefficient. The muscles of primary interest were the lateral and medial hamstrings. A coin toss determined that the medial hamstring data would be chosen for the reliability calculations. Random selection also determined that the data would be measured at the 30° angle. Measurements were taken from the chart recordings of 10 subjects. The charts were coded so that the investigator was not aware of which chart was being measured until all measurements had been taken. The charts were shuffled after the first measurements were recorded for all 10 subjects.

The following data were collected and a Pearson product moment correlation was performed.

<u>SUBJECT</u>	<u>TRIAL 1</u>	<u>TRIAL 2</u>
1(15)	20.5	20.5
2(9)	19.0	19.0
3(8)	21.5	21.5
4(17)	27.0	27.0
5(11)	15.0	15.0
6(10)	25.5	25.5
7(7)	12.0	11.5
8(18)	16.5	16.5
9(12)	24.5	24.5
10(19)	21.0	21.0

$$r_r = 0.99$$

Reliability Calculation for Pendulum Goniometry

The accuracy of the investigator's measurement technique was ascertained prior to data collection. Accuracy for the pendulum goniometric measurements was determined by calculating percent error. This procedure involved performance of ten measurements of the same angle of the knee. Following each measurement the knee was returned to the starting position, which was 0° of knee flexion, and then was returned to the prescribed 20° angle as indicated by the triggering of the pen deflector on the torque channel. The isokinetic speed dial was turned to 0°/s at this time to stabilize the lower limb so as to allow for accurate reading of the goniometer's gravity-dependent dial. The investigator read and recorded each of the 10 angular measurements shown on the goniometer dial. The average deviation (AD) from each of the scores was determined by finding the absolute difference between each individual score and the mean of all scores. The absolute differences were then summed and averaged. The percent error formula was:

$$\% \text{ error} = \frac{100 (\text{AD})}{\bar{x}}$$

According to Weber and Lamb¹³, if a measuring technique has a value of 3% or less for percent error, it is

considered to have acceptable accuracy (refer to Table 21).

Reference

Weber JC, Lamb DR: Statistics and Research in Physical Education. St. Louis: C.V. Mosby Co., 1970

Table 21. Percent error calculation for pendulum
goniometry

Repetition	Scope	AD
1	20.5°	0.1
2	20.0°	0.4
3	20.0°	0.4
4	20.0°	0.4
5	20.5°	0.1
6	21.0°	0.6
7	20.5°	0.1
8	20.5°	0.1
9	20.5°	0.1
10	20.5°	0.1
Σ 204.0°		Σ 2.40
$\bar{x} = 20.4^\circ$		$\overline{AD} = 0.24$

% error = 1.18%

APPENDIX 4

SUBJECT RAW DATA

MUSCLE: GASTROCNEMIUS - NORMAL TIBIAL POSITION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	90.00	141.00	173.00	216.00
2	24.00	167.00	165.00	257.00
3	66.00	89.00	74.00	59.00
4	7.00	57.00	207.00	343.00
5	45.00	71.00	85.00	75.00
6	11.00	116.00	121.00	232.00
7	18.00	109.00	127.00	173.00
8	10.00	53.00	82.00	103.00
9	45.00	59.00	68.00	101.00
10	10.00	77.00	197.00	252.00
11	4.00	113.00	98.00	140.00
12	13.00	54.00	62.00	94.00
13	12.00	108.00	173.00	227.00
14	10.00	103.00	70.00	123.00
15	80.00	123.00	193.00	207.00
16	28.00	89.00	100.00	75.00
17	8.00	69.00	108.00	171.00
18	64.00	214.00	329.00	379.00
19	21.00	53.00	71.00	106.00
TOTAL	624	1995	2733	3333
$\bar{x}/S.D.$	31.2/28.1	99.8/42.2	136.7/70	175.4/91.4
s.s.	34514	232811	467003	735213

MUSCLE: GASTROCNEMIUS - EXTERNAL ROTATION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	69.00	100.00	173.00	194.00
2	82.00	173.00	180.00	184.00
3	71.00	71.00	61.00	56.00
4	0.00	60.00	143.00	233.00
5	30.00	59.00	72.00	73.00
6	21.00	142.00	147.00	268.00
7	18.00	127.00	155.00	191.00
8	5.00	53.00	79.00	74.05
9	40.00	74.00	92.00	118.00
10	6.00	90.00	184.00	197.00
11	21.00	89.00	83.00	117.00
12	10.00	40.00	50.00	63.00
13	10.00	94.00	169.00	206.00
14	30.00	80.00	80.00	113.00
15	84.00	91.00	123.00	159.00
16	17.00	59.00	56.00	42.00
17	6.00	58.00	110.00	169.00
18	18.00	89.00	229.00	389.00
19	24.00	57.00	129.00	163.00
TOTAL	639	1738	2488	3009
$\bar{x}/S.D.$	31.95/28.3	86.9/34.16	124.4/51.3	158.37/85.1
s.s.	35603	173206	359604	607119

MUSCLE: GASTROCNEMIUS - INTERNAL ROTATION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	67.00	106.00	143.00	184.00
2	27.00	94.00	145.00	224.00
3	37.00	47.00	84.00	69.00
4	7.00	80.00	193.00	313.00
5	30.00	63.00	77.00	80.00
6	11.00	100.00	111.00	258.00
7	5.00	59.00	105.00	195.00
8	11.00	42.00	74.00	103.00
9	42.00	74.00	93.00	100.00
10	19.00	90.00	203.00	265.00
11	15.00	115.00	134.00	143.00
12	23.00	69.00	75.00	110.00
13	12.00	114.00	225.00	227.00
14	10.00	88.00	90.00	190.00
15	39.00	59.00	59.00	170.00
16	16.00	63.00	58.00	48.00
17	15.00	44.00	188.00	187.00
18	21.00	132.00	261.00	507.00
19	20.00	33.00	64.00	63.00
TOTAL	479	1579	2609	3436
$\bar{x}/S.D.$	24.0/16.2	79.00/28.0	130.45/64.20	180.84/109.18
s.s.	16473	139545	418629	835954

MUSCLE: LATERAL HAMSTRING - NORMAL

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	56.00	76.00	101.00	121.00
2	10.00	67.00	56.00	45.00
3	52.00	156.00	222.00	259.00
4	4.00	81.00	136.00	112.00
5	65.00	65.00	64.00	57.00
6	5.00	65.00	74.00	56.00
7	12.00	100.00	116.00	76.00
8	1.00	100.00	103.00	99.00
9	55.00	83.00	94.00	55.00
10	4.00	77.00	75.00	44.00
11	13.00	101.00	131.00	100.00
12	27.00	130.00	151.00	193.00
13	18.00	86.00	92.00	88.00
14	9.00	89.00	77.00	83.00
15	59.00	92.00	102.00	70.00
16	40.00	92.00	73.00	49.00
17	15.00	55.00	115.00	94.00
18	28.00	80.00	104.00	49.00
19	48.00	88.00	316.00	372.00
TOTAL	586	1797	2346	2022
$\bar{x}/S.D.$	293.3/23.11	89.85/23.49	117.31/60.15	106.42/83.94
s.s.	27314	171941	343936	342018

MUSCLE: LATERAL HAMSTRING - EXTERNAL ROTATION

(Values expressed in %EMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	69.00	87.00	124.00	127.00
2	33.00	66.00	59.00	49.00
3	70.00	181.00	289.00	185.00
4	0.00	64.00	108.00	76.00
5	69.00	73.00	75.00	63.00
6	8.00	60.00	73.00	69.00
7	8.00	167.00	141.00	100.00
8	2.00	101.00	104.00	72.00
9	62.00	80.00	83.00	62.00
10	2.00	108.00	85.00	48.00
11	26.00	109.00	125.00	95.00
12	24.00	146.00	185.00	218.00
13	15.00	103.00	98.00	78.00
14	16.00	131.00	131.00	98.00
15	88.00	138.00	150.00	105.00
16	18.00	91.00	80.00	51.00
17	11.00	63.00	113.00	98.00
18	13.00	86.00	108.00	61.00
19	48.00	136.00	448.00	448.00
TOTAL	696	2147	2707	2103
$\bar{x}/S.D.$	34.8/32.98	107.35/37.12	135.35/88.96	110.68/93.01
S.S.	44882	256667	516843	388485

MUSCLE: LATERAL HAMSTRING - INTERNAL ROTATION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	60.00	80.00	94.00	133.00
2	12.00	51.00	52.00	55.00
3	74.00	126.00	193.00	207.00
4	1.00	53.00	101.00	77.00
5	65.00	76.00	65.00	63.00
6	3.00	56.00	69.00	55.00
7	0.00	39.00	112.00	71.00
8	3.00	84.00	84.00	86.00
9	55.00	68.00	61.00	53.00
10	1.00	56.00	59.00	52.00
11	10.00	52.00	62.00	55.00
12	34.00	97.00	127.00	114.00
13	15.00	78.00	98.00	75.00
14	5.00	72.00	75.00	77.00
15	19.00	100.00	123.00	83.00
16	5.00	67.00	73.00	50.00
17	18.00	46.00	128.00	101.00
18	10.00	68.00	79.00	61.00
19	24.00	28.00	144.00	348.00
TOTAL	440	1396	1905	1816
$\bar{x}/S.D.$	22.0/23.37	6.98/23.72	95.25/35.23	95.58/71.82
S.S.	20058	108130	205035	2266426

MUSCLE: MEDIAL HAMSTRING - NORMAL ROTATION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	90.00	98.00	80.00	62.00
2	16.00	80.00	81.00	104.00
3	52.00	95.00	105.00	95.00
4	8.00	87.00	149.00	131.00
5	83.00	83.00	68.00	75.00
6	4.00	79.00	107.00	100.00
7	8.00	142.00	184.00	100.00
8	2.00	108.00	89.00	88.00
9	55.00	56.00	62.00	45.00
10	9.00	97.00	94.00	87.00
11	9.00	108.00	103.00	86.00
12	20.00	145.00	138.00	125.00
13	16.00	106.00	101.00	76.00
14	7.00	105.00	123.00	131.00
15	80.00	103.00	86.00	58.00
16	43.00	100.00	93.00	79.00
17	5.00	76.00	116.00	95.00
18	15.00	75.00	95.00	54.00
19	13.00	94.00	206.00	259.00
TOTAL	590	1937	2204	1850
$\bar{x}/S.D.$	29.5/29.3	96.85/20.96	110.2/36.39	97.37/46.11
S.S.	33682	195897	268038	218394

MUSCLE: MEDIAL HAMSTRING - EXTERNAL ROTATION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	67.00	97.00	71.00	70.00
2	36.00	71.00	74.00	86.00
3	46.00	79.00	93.00	31.00
4	0.00	77.00	119.00	112.00
5	77.00	80.00	70.00	61.00
6	3.00	84.00	121.00	123.00
7	5.00	118.00	134.00	118.00
8	4.00	79.00	85.00	61.00
9	44.00	53.00	58.00	49.00
10	7.00	90.00	95.00	59.00
11	19.00	76.00	72.00	73.00
12	15.00	112.00	132.00	102.00
13	10.00	67.00	75.00	58.00
14	26.00	88.00	118.00	127.00
15	48.00	84.00	76.00	59.00
16	11.00	83.00	75.00	55.00
17	4.00	67.00	108.00	90.00
18	9.00	50.00	72.00	40.00
19	13.00	138.00	225.00	284.00
TOTAL	497	1670	1955	1658
$\bar{x}/S.D.$	24.85/23.37	83.5/20.97	97.75/37.76	87.26/55.57
s.s.	22727	147802	218193	200266

MUSCLE: MEDIAL HAMSTRING - INTERNAL ROTATION

(Values expressed in %IEMG)

Subject	ANGLE			
	10°	30°	60°	90°
1	94.00	91.00	76.00	72.00
2	20.00	94.00	126.00	91.00
3	69.00	90.00	88.00	66.00
4	2.00	94.00	143.00	146.00
5	74.00	106.00	84.00	74.00
6	1.00	80.00	120.00	121.00
7	0.00	114.00	222.00	139.00
8	2.00	112.00	118.00	86.00
9	53.00	66.00	50.00	51.00
10	12.00	91.00	107.00	94.00
11	13.00	118.00	144.00	88.00
12	22.00	153.00	160.00	132.00
13	13.00	93.00	109.00	98.00
14	8.00	141.00	151.00	172.00
15	25.00	103.00	102.00	64.00
16	8.00	103.00	120.00	79.00
17	5.00	67.00	138.00	115.00
18	82.00	84.00	84.00	55.00
19	13.00	56.00	228.00	266.00
TOTAL	569	1972	2505	2009
$\bar{x}/S.D.$	28.45/30.39	98.6/23.67	125.25/44.03	105.74/50.93
s.s.	33737	205084	350589	259107

TORQUE CHANNEL: NORMAL ROTATION

(Values expressed in %torque)

Subject	ANGLE			
	10°	30°	60°	90°
1	119.00	119.00	83.00	58.00
2	37.00	86.00	64.00	43.00
3	113.00	138.00	91.00	58.00
4	0.00	88.00	81.00	53.00
5	84.00	83.00	57.00	32.00
6	1.00	124.00	100.00	59.00
7	0.00	94.00	64.00	35.00
8	0.00	96.00	63.00	34.00
9	84.00	68.00	59.00	32.00
10	0.00	95.00	78.00	41.00
11	0.00	104.00	87.00	66.00
12	0.00	100.00	78.00	51.00
13	0.00	114.00	85.00	42.00
14	0.00	87.00	59.00	44.00
15	86.00	98.00	70.00	37.00
16	67.00	101.00	76.00	38.00
17	0.00	71.00	80.00	45.00
18	52.00	97.00	61.00	28.00
19	0.00	92.00	115.00	80.00
TOTAL	743	1957	1524	876
$\bar{x}/S.D.$	37.15/45.54	97.85/16.73	76.2/15.02	46.11/13.47
s.s.	67001	196815	120416	43656

TORQUE CHANNEL - EXTERNAL ROTATION

(Values expressed in %torque)

Subject	ANGLE			
	10°	30°	60°	90°
1	104.00	113.00	74.00	60.00
2	50.00	86.00	60.00	35.00
3	109.00	121.00	87.00	30.00
4	0.00	93.00	93.00	59.00
5	89.00	82.00	66.00	39.00
6	0.00	141.00	107.00	66.00
7	0.00	88.00	65.00	38.00
8	1.00	94.00	61.00	29.00
9	77.00	76.00	65.00	37.00
10	0.00	88.00	73.00	34.00
11	2.00	104.00	85.00	59.00
12	0.00	103.00	83.00	61.00
13	0.00	110.00	79.00	43.00
14	38.00	85.00	62.00	43.00
15	90.00	95.00	67.00	45.00
16	33.00	81.00	58.00	28.00
17	0.00	78.00	76.00	54.00
18	20.00	79.00	57.00	18.00
19	0.00	120.00	125.00	95.00
TOTAL	714	1933	1500	873
$\bar{x}/S.D.$	35.7/42.79	96.65/17.19	75.00/17.84	45.95/17.88
s.s.	60286	192437	118550	45867

TORQUE CHANNEL: INTERNAL ROTATION

(Values expressed in %torque)

Subject	ANGLE			
	10°	30°	60°	90°
1	74.00	99.00	71.00	--
2	0.00	82.00	58.00	40.00
3	92.00	128.00	91.00	38.00
4	0.00	76.00	86.00	42.00
5	71.00	89.00	67.00	39.00
6	3.00	127.00	99.00	70.00
7	0.00	61.00	69.00	31.00
8	0.00	88.00	61.00	34.00
9	67.00	75.00	44.00	22.00
10	0.00	88.00	66.00	41.00
11	0.00	81.00	58.00	35.00
12	0.00	89.00	73.00	48.00
13	0.00	114.00	93.00	56.00
14	0.00	87.00	59.00	33.00
15	33.00	101.00	76.00	41.00
16	0.00	82.00	60.00	22.00
17	0.00	51.00	86.00	50.00
18	36.00	89.00	53.00	22.00
19	0.00	43.00	113.00	63.00
TOTAL	495	1763	1461	783
$\bar{x}/S.D.$	24.75/38.23	88.15/22.09	73.05/17.62	41.21/13.44
s.s.	40025	164681	112625	35519

APPENDIX 5

COMPARISON OF SURFACE AND WIRE EMG RECORDINGS

A comparison of the electrical activity of the medial and lateral hamstring muscles was made using surface and wire electrodes simultaneously for both groups.

Theoretically, the surface and wire recordings from the same muscle group should be of similar shape because they are detecting electrical activity from the same contracting musculature. In addition, these recordings should differ from those detected and recorded from another muscle or muscle group. In the present study, the motor points for biceps femoris and semitendinosus were found and marked.

The surface electrodes were aligned as previously described for all subjects. Additionally, a bipolar wire electrode was inserted into each muscle, at their respective motor points, using a 26.5 gauge hypodermic needle. The wires and needle were previously sterilized and the point of entry of the needle was cleaned and soaked thoroughly with 70% alcohol, prior to insertion and following withdrawal.

After all electrodes were secured to the skin with adhesive strips, the subject was situated on the Cybex table and was prepared for performance of several submaximal and maximal knee flexor contractions similar to the actual test conditions. Simultaneous recordings on the Hewlett Packard recorder (Figure 30) confirmed that the signals from the medial and lateral hamstring groups were different from each other in shape and in location of maximal IEMG amplitude. Conversely, surface and wire EMG for the same

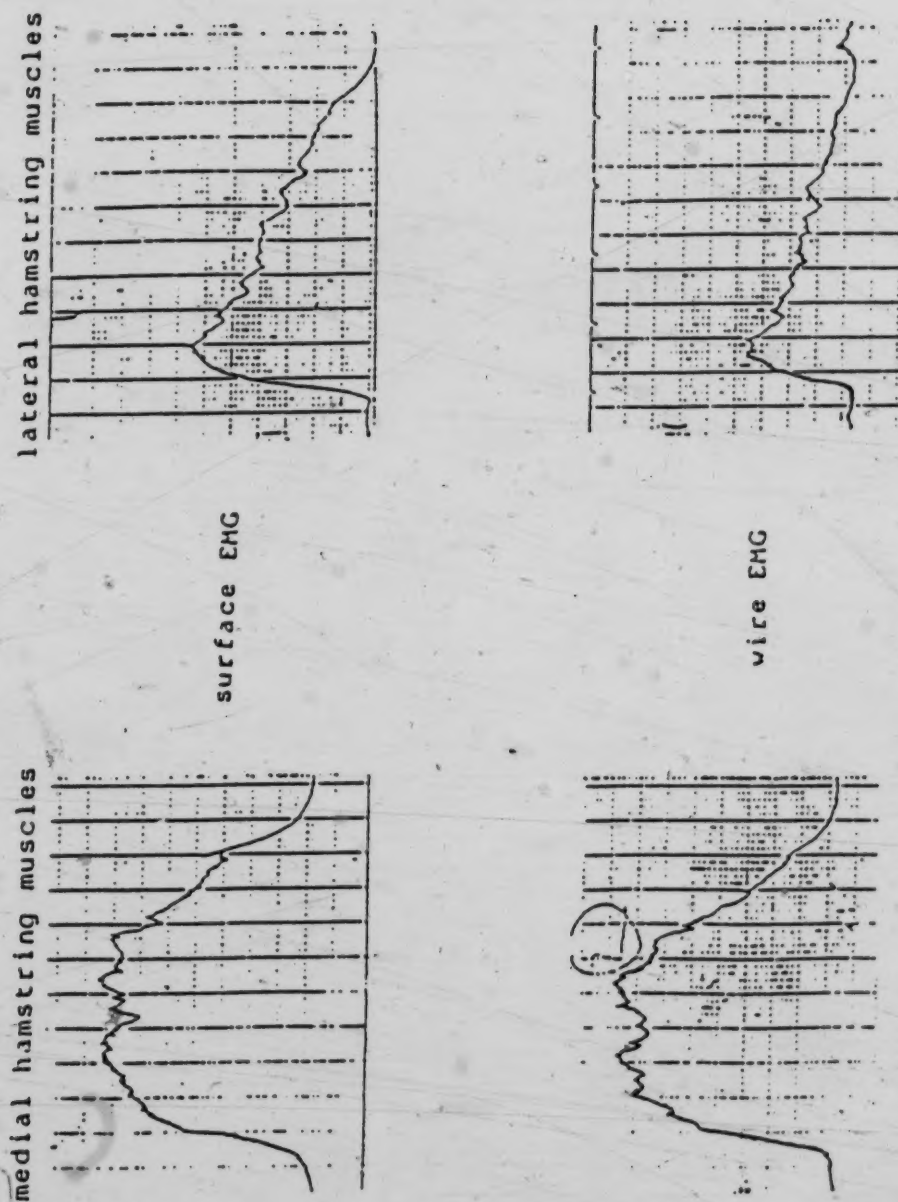


Figure 30. Chart recording of simultaneous wire and surface EMG activity of the lateral and medial hamstring muscle groups, as determined in one subject.

muscle groups were virtually identical in pattern, although different in amplitude.

These findings strengthen the research hypothesis and verify the technique of electrode placement used in the study.

Reference

Hof AL, Van Den Berg JW: Linearity between the weighted sum of the EMGs of the human triceps surae and the torque. J Biomech 10: 529-539, 1977
